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Agricultural Scene Understanding

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Final Report

Vol. I Agricultural Scene Understanding

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16. Abstract
Results of four investigations, all related to agricultural remote sensing are described. The four tasks are: (A) Analysis of Agronomic and Spectral Data for Physical Understanding, (B) Field Measurements Data Management, (C) Multicrop Supporting Field Research, and (D) Determining the Climatic and Genetic Effects on the Relationships Between Multispectral Reflectance and Physical-Chemical Properties of Soils.

A. The Analysis of Agronomic-Spectral Data report describes the results of analyses of LACIE Field Research Data, including the relationships of agronomic and reflectance characteristics of wheat canopies, effect of cultural and environmental factors on reflectance properties of wheat, and discrimination of wheat and other crops as a function of wavelength band selection and acquisition date.

B. The Field Measurements Data Management report describes field research data base developed at LARS including the development of graphical and statistical analysis software, data processing software, and distribution of data.

C. The Multicrop Supporting Field Research report describes the measurements of spectral characteristics of corn and soybeans and development of a multispectral data acquisition system for field research.

D. The fourth report describes the objectives, experimental approach, and initial results of a study of the relationships between the reflectance and physical-chemical properties of over 400 different soils.

17. Key Words (Suggested by Author(s))
LACIE, crop inventory, soil mapping, field research, reflectance measurements, spectral characteristics of crops and soils, agricultural remote sensing, multispectral remote sensing.

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A. Analysis of Agronomic and Spectral Data For Physical Understanding*

Crop identification and area estimation promises to be one of the major applications of remote sensing and the Large Area Crop Inventory Experiment (LACIE) has pushed the technology to near operational use for wheat (MacDonald and Hall, 1978). Remote sensing also offers great potential for obtaining accurate and timely information about the condition and yield of crops (Bauer, 1975).

To fully realize the potential of remote sensing for crop identification, condition assessment, and yield prediction it is important to understand and quantify the relation of agronomic characteristics of crops to their multispectral reflectance properties. For example, it is essential to know in which regions of the spectrum information relating to variations in crop parameters is contained. This information is necessary for the optimum use of current Landsat technology, as well as for the design and development of future remote sensing systems.

Differences among crop species and dynamic changes due to growth, development, stress, and varying cultural practices cause differences in the reflectance spectra of crops. Many of the factors affecting the reflectance properties of plant leaves have been identified and investigated utilizing laboratory measurements. The relationships of physical-biological parameters such as chlorophyll concentration, water content and leaf morphology to reflectance, transmittance and absorption have been well-established for leaves. Some of the papers and reviews describing these relationships include: Gates et al. (1965), Breece and Holmes (1971), Gausman et al. (1970), and Sinclair et al. (1971).

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*This section describing the results of Task 1A, Analysis of Spectral Data for Physical Understanding, was prepared by the task leaders, Dr. Marvin Bauer and Marilyn Hixson. Drs. Craig Daughtry, Virgil Anderson, and Vern Vanderbilt made valuable contributions to the experiment design, data analysis, and interpretation of results. Graduate assistants, John Ahlrichs, Don Crecelius, Jeff Kollenkark, and Christina Stellon conducted many of the analyses.

Knowledge of the reflectance characteristics of single leaves is basic to understanding the reflectance properties of crop canopies in the field, but cannot be applied directly since there are significant differences in the spectra of single leaves and canopies. The reflectance characteristics of canopies are considerably more complex than those of single leaves because there are many more interacting variables in canopies. Some of the more important agronomic parameters influencing the reflectance of field-grown canopies are: leaf area index, biomass, leaf angle, soil cover percentage, soil color, and leaf color. Differences in these parameters are caused by variations in many cultural and environmental factors, including planting date, cultivar, seeding rate, fertilization, soil moisture, and temperature. Solar elevation and azimuth angle and the view angle and direction of the sensor also affect the measured reflectance of crops and soils.

The spectral and agronomic measurements which have been acquired during the three years of the LACIE field research program are being analyzed to provide an understanding of the relationship of reflectance to the biological and physical characteristics of crops and soils. The primary data being analyzed are the spectrometer data acquired by the truck-and helicopter-borne systems. These data are particularly useful because the spectral data were acquired in 0.01 μm wavelength intervals and are calibrated in terms of bidirectional reflectance faction. Having the entire spectrum from 0.4 to 2.4 μm permits simulation of the response in any specified waveband. In other words, the analysis is not restricted to a fixed set of bands such as Landsat MSS or one of the aircraft scanner systems. Calibration of the data permits valid comparisons to be made among different dates, locations, and sensors.

The overall objective of the analyses being conducted is to quantitatively determine the spectral-temporal characteristics of wheat, small grains, and other agricultural crops. The specific objectives of the analyses reported here are:

1. To determine the relationship of agronomic variables such as biomass and leaf area index to the multispectral reflectance of spring wheat and evaluate the potential for predicting the agronomic characteristics of wheat canopies from reflectance measurements.

2. To examine the effects of cultural and environmental factors on the spectral response of spring wheat.

3. To determine the discriminability of wheat and other crops as a function of acquisition date and spectral band selection.

1. PREDICTION OF AGRONOMIC CHARACTERISTICS OF SPRING WHEAT CANOPIES FROM REFLECTANCE MEASUREMENTS

One of the major long term goals of agricultural remote sensing research is to estimate or predict crop variables that can subsequently be used to assess crop growth and vigor or be entered into a yield production model. To achieve this goal the relationship between the spectral reflectance of crop canopies and their biological and physical characteristics must be understood. Therefore, the relationships of canopy variables to multispectral reflectance were first investigated. This information was then used to develop regression equations for predicting canopy variables from reflectance data. The analyses were performed using wavelength bands of the current and future satellite multispectral scanner systems.

1.1 Experimental Approach

The data used for these analyses were collected using a truck-mounted spectrometer during the first two years of the LACIE field research program at the agriculture experiment station at Williston, North Dakota. Measurements were made at approximately weekly intervals of the bidirectional reflectance factor and agronomic characteristics of 32 plots of spring wheat (Bauer *et al.*, 1978). The design of the experiment was a 2^4 factorial with two replications. The factors and levels were:

Soil Moisture: (1) wheat during previous year, (2) fallow during previous year.

Planting Date: (1) early, (2) late

Cultivar: (1) standard height, (2) semi-dwarf.

Nitrogen Fertilization: (1) none, (2) 34kg/ha

The factors and levels were selected to represent regional agricultural practices that affect the growth, development, and yield of spring wheat. The treatments resulted in a relatively wide range of types of wheat canopies, differing in maturity, biomass, and percent soil cover at any one time and over the season.

In addition to reflectance, the following agronomic variables were measured: maturity stage, height, percent soil cover, leaf area index, percent green leaves, fresh and dry biomass, and plant water content (difference between fresh and dry biomass). Vertical and oblique photographs were taken of each plot on each measurement date.

After processing, graphs of the spectral data were examined to verify data quality and qualitatively assess the information contained in the spectra. Correlation and regression analyses were used to relate biological and physical variables describing the canopies to spectral response.

Since the application of remotely sensed spectral measurements will be with multispectral scanner systems which measure the spectral response in selected wavelength bands, the statistical analyses were performed using wavelength bands. Two different sets of bands were considered, Landsat MSS and Landsat thematic mapper. The thematic mapper is a second generation satellite multispectral scanner system planned for Landsat-D which is to be launched in 1981. The Landsat MSS bands are: 0.5-0.6 (green), 0.6-0.7 (red), 0.7-0.8(near infrared), and 0.8-1.1 μm (near infrared). The thematic mapper bands which are narrower and sample more parts of the spectrum are: 0.45-0.52(blue), 0.52-0.60 (green), 0.63-0.69(red), 0.76-0.90 (near infrared), 1.55-1.75 (middle infrared), and 2.08-2.35μm (middle infrared). The thematic mapper will also have a thermal infrared band, but thermal measurements were not acquired for this experiment.

1.2 Results and Discussion

Relation of Canopy to Variables to Multispectral Reflectance

The amount of vegetation present is one of the principal factors influencing the reflectance of crop canopies. Figure A-1 illustrates the effect of amount of vegetation as measured by leaf area index, biomass, and percent soil cover on the spectral response during the period between tillering and the beginning of heading when the maximum green leaf area was reached. As leaf area and biomass increase there is a progressive and characteristic decrease in the reflectance of the chlorophyll absorption region, increase in the near infrared reflectance, and decrease in the middle infrared reflectance.

The relationships between several agronomicaly important characteristics of crop canopies and reflectances in selected wavelength bands are illustrated in Figures A-2 to A-5. These plots include data from all treatments when green leaves were present (seedling through flowering stages of maturity). Plotting the spectral reflectance versus canopy variables allows visual assessment of the relation of canopy variables and reflectance, and permits better interpretation of the correlation analyses (Table A-1). It should be noted that a portion of the scatter in the data is associated with various agronomic treatments, as well as measurement errors in the independent and dependent variables.

The relationships between the 0.63-0.69 and 0.6-0.7 μm reflectances and green vegetation results from the strong absorption of incident radiation by the chlorophylls . Reflectance in these wavelength bands is inversely related to the amount of chlorophyll present in the vegetative canopy and thus is sensitive to green or photosynthetically active vegetation.

The relationship of the near infrared wavelength bands, 0.76-0.90 and 0.8-1.1μm, results from the lack of absorption and high degree of scattering of near infrared radiation by green leaves. Over the ranges

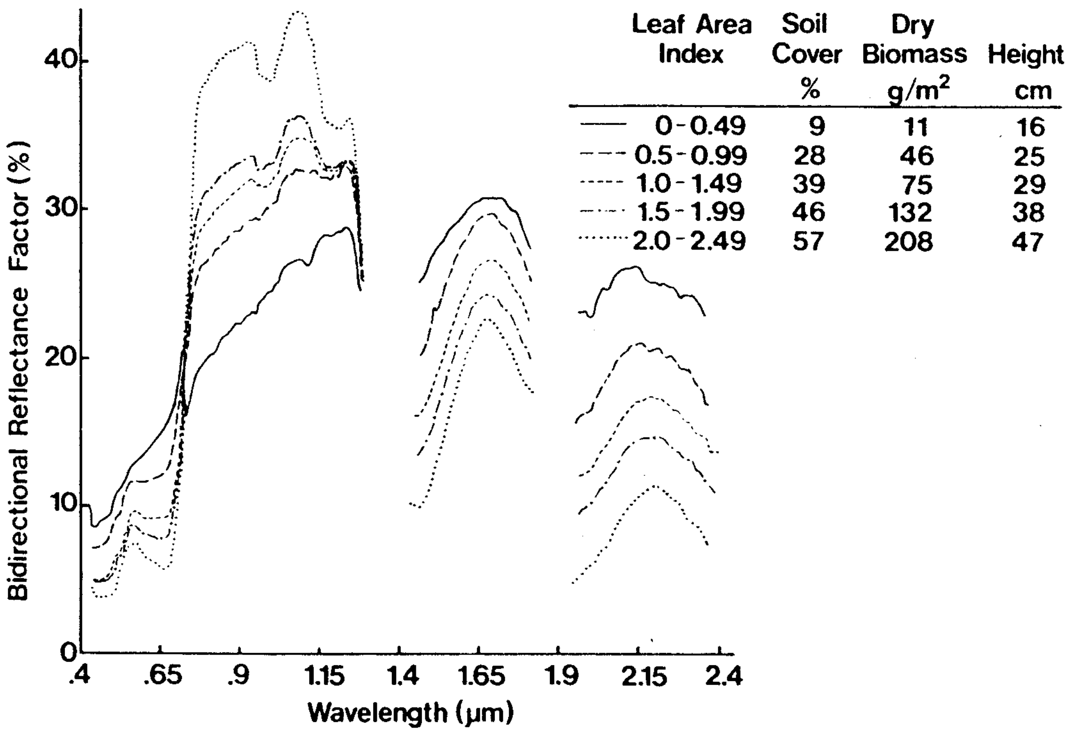

Figure A-1. Effect of leaf area index, percent soil cover, dry biomass, and plant height on the spectral reflectance of spring wheat during the period between tillering and the beginning of heading, when the maximum green leaf area is reached. Data were acquired at Williston, North Dakota on May 28 - June 18, 1976 and include plots with different soil moisture levels, planting dates, nitrogen fertilization and cultivars.

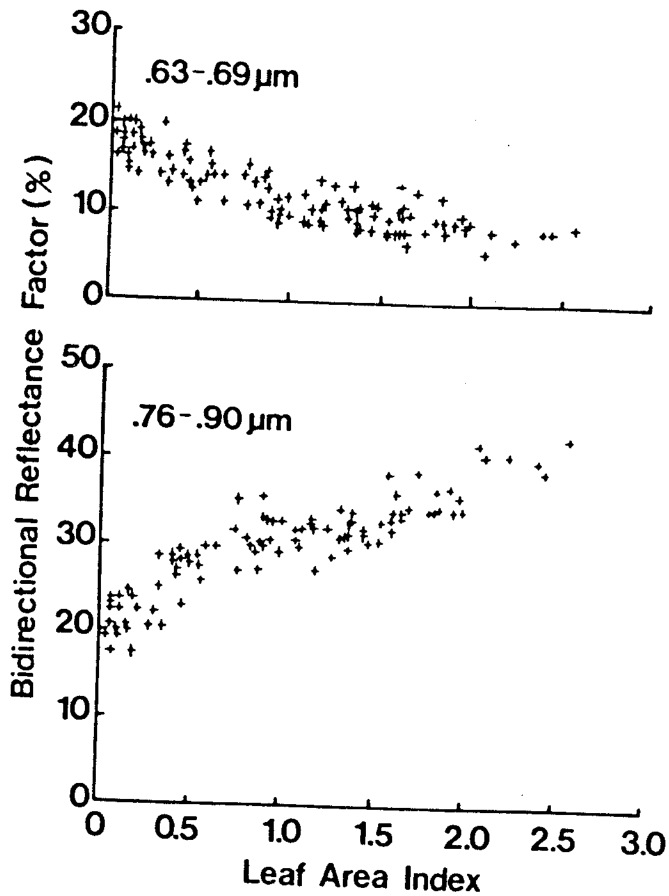

Figure A-2. Relationship of leaf area index to reflectances in the chlorophyll absorption (0.63-0.69 μm) and near infrared (0.76-0.90 μm) regions. Measurements for seedling through flowering stages of maturity are included for 16 treatments representing different levels of soil moisture availability, planting dates, nitrogen fertilization, and cultivar.

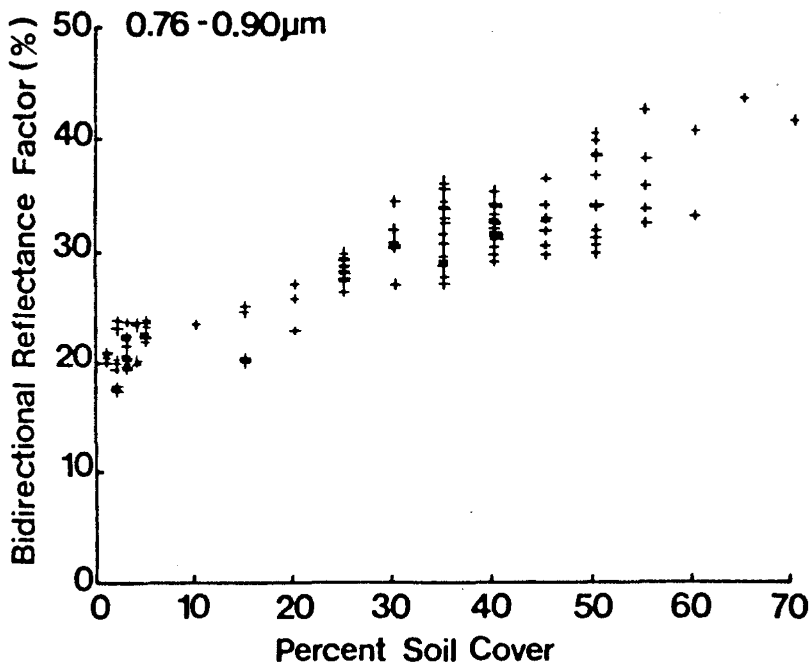

Figure A-3. Relationship of percent soil cover to near infrared reflectance of spring wheat canopies.

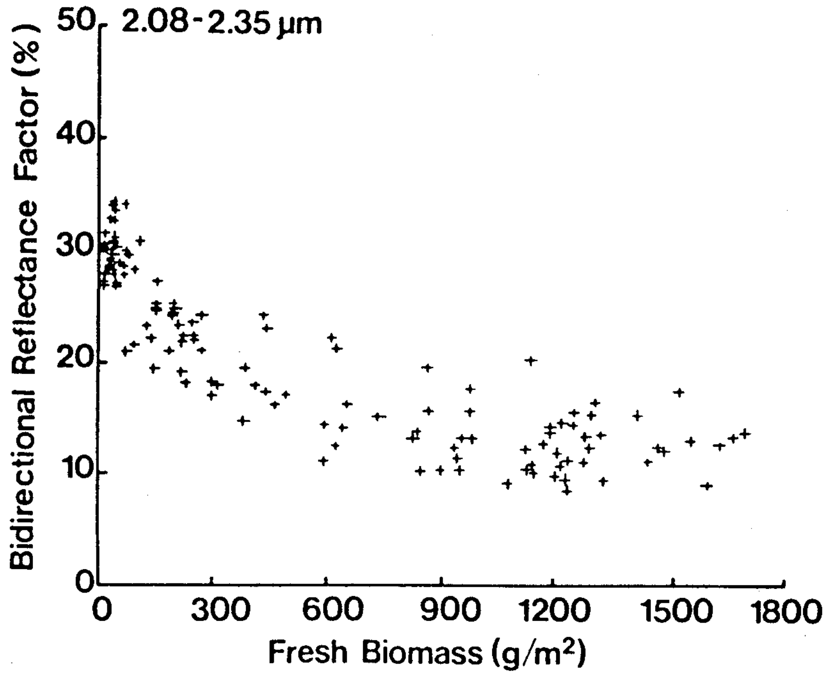

Figure A-4. Relationship of fresh biomass to middle infrared reflectance of spring wheat canopies.

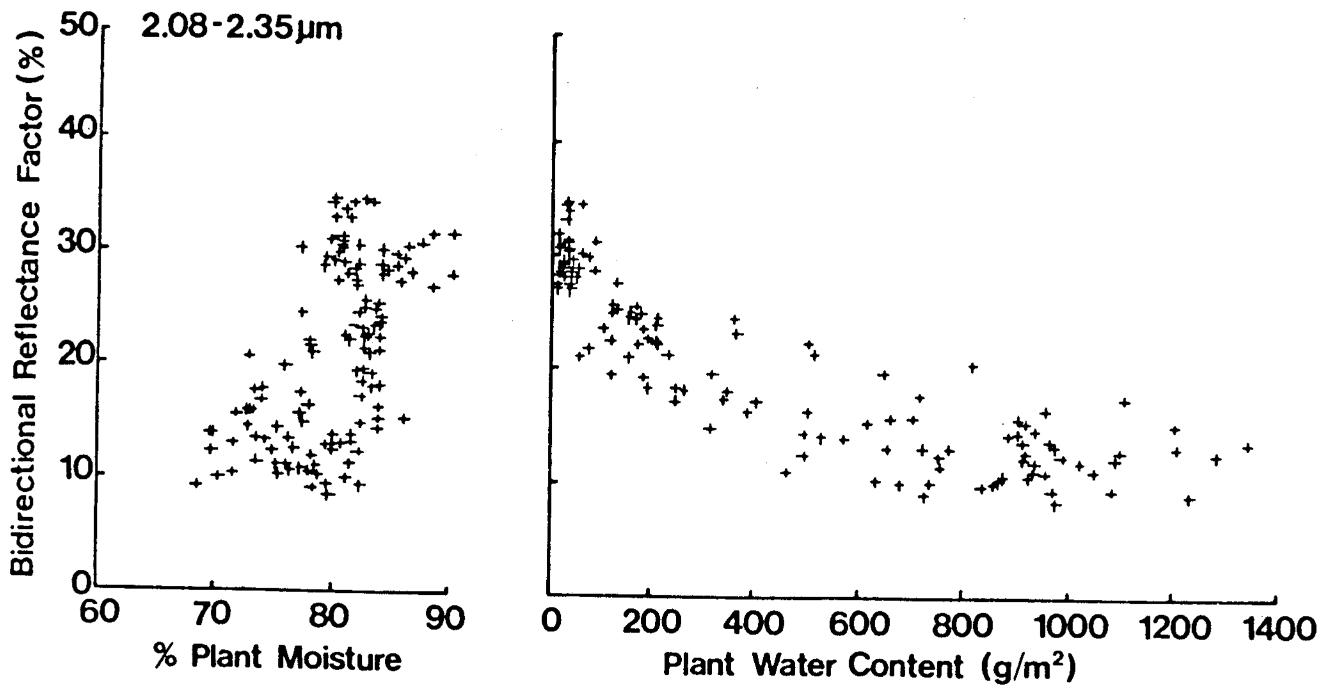

Figure A-5. Relationship of two measures of plant moisture, percent plant moisture and plant water content, to middle infrared reflectance of spring wheat canopies.

of our data there is a nearly linear relationship between the near infrared reflectance and the amount of green vegetation present.

Reflectances in the middle infrared wavelength bands, 1.55-1.75 and 2.08-2.35 μm, are strongly influenced by plant moisture. The reflectances are inversely related in a nonlinear manner to the amount of plant moisture present in the canopy.

As a way of summarizing these relationships the linear correlations of five different canopy variables with the Landsat MSS and thematic mapper wavelength bands are shown in Table A-1. A near infrared wavelength band, 0.76-0.90 μm, is most highly correlated with percent soil cover and leaf area index. While the middle infrared band, 2.08-2.35 μm, has the highest correlation of the six individual thematic mapper bands with fresh biomass, dry biomass, and plant water, and is highly correlated with leaf area index and percent soil cover. These results illustrate the importance of making measurements in several regions of the spectrum, especially in the middle infrared wavelength region which is not measured by the present Landsat multispectral scanners.

The correlations of the Landsat MSS and the proposed thematic mapper bands with the crop canopy variables can be compared in Table A-1. The correlation of canopy variables with each Landsat MSS band is less than with the corresponding thematic mapper band. Although the differences in correlation coefficients between the Landsat MSS and thematic mapper bands are relatively small, the coefficients for the thematic mapper bands are consistently higher. The higher correlations for the thematic mapper bands are attributed to more optimal width and location of bands with respect to the spectral characteristics of vegetation.

For example, the data in Table A-1 demonstrate a disadvantage of collecting data in the 0.7-0.8 μm wavelength region. The inclusion of the region of rapid transition from the chlorophyll absorption region of the spectrum to the highly reflecting near infrared region (0.70-0.74 μm) results in a weaker relation between reflectance and the crop canopy

Table A-1. The linear correlations of reflectances in the thematic mapper and Landsat MSS wavelength bands with percent soil cover, leaf area index, fresh and dry biomass, and plant water content.

Wavelength Band (μm)	Percent Soil Cover	Leaf Area Index	Fresh Biomass	Dry Biomass	Plant Water Content
Thematic Mapper					
0.45-0.52	-0.82	-0.79	-0.75	-0.69	-0.76
0.52-0.60	-0.82	-0.78	-0.81	-0.77	-0.82
0.63-0.69	-0.91	-0.86	-0.80	-0.73	-0.81
0.76-0.90	0.93	0.92	0.76	0.67	0.79
1.55-1.75	-0.85	-0.80	-0.83	-0.79	-0.84
2.08-2.35	-0.91	-0.85	-0.86	-0.81	-0.86
Landsat MSS					
0.5-0.6	-0.82	-0.79	-0.81	-0.76	-0.81
0.6-0.7	-0.90	-0.85	-0.81	-0.74	-0.82
0.7-0.8	0.84	0.84	0.57	0.46	0.60
0.8-1.1	0.91	0.90	0.77	0.68	0.79

Table A-2. The linear correlations of ratios and other transformations of reflectance measurements with agronomic characteristics of spring wheat canopies.

Transformation	Percent Soil Cover	Leaf Area Index	Fresh Biomass	Dry Biomass	Plant Water Content
IR/Red*	.89	.90	.76	.67	.78
Red/IR	-.94	-.87	-.80	-.73	-.81
IR + Red	.65	.68	.48	.40	.51
IR - Red	.95	.93	.81	.72	.83
Vegetation Index	.95	.90	.82	.74	.83
Transformed Veg. Index	.95	.89	.82	.74	.83
Greenness	.67	.70	.46	.36	.48
Brightness	.90	.89	.68	.58	.70

*Red- 0.63-0.69 μm, IR - 0.76-0.90 μm

variables. Similar results were reported by Tucker and Maxwell (1975). This region of low correlation reduces the ability of the 0.7-0.8 μm wavelength region to estimate crop canopy variables. The 0.8-1.1 μm wavelength band has a greater correlation with each of the agronomic factors than the 0.7-0.8 μm wavelength band, and the 0.76-0.90 μm wavelength band has a correlation with each agronomic factor that is greater then either the 0.7-0.8 or the 0.8-1.1 μm wavelength bands.

Several investigators have examined the use of ratios, particularly infrared/red, and other transformations of two or more spectral bands to enhance the relationship between spectral and agronomic properties of vegetative canopies. Most of the investigations have been performed using Landsat MSS data, although the work of Tucker (1977) has been with field measurements of radiance. Compared to single wavelength bands these investigators have generally found stronger relationships using infrared/red rations, radiance differences, various vegetation indices, and the greenness-brightness transformation.

Several transformations of the red and near infrared reflectances were evaluated in our study. These included the ratios, differences, and sums of the two bands. In addition, transformations involving measurements in two visible and two infrared bands were evaluated. These included the vegetation index and transformed vegetation index developed by Rouse et al., (1973) and the tasseled cap transformations into greenness and brightness developed by Kauth and Thomas, (1976).

Several conclusions can be drawn from the results (Table A-2) of the analyses. The infrared/red ratio is sensitive to the amount of green vegetation present, as is the red/infrared ration. The difference between the two bands is also highly correlated with the several measures of the amount of vegetation present, but their sum is not. The correlations with the vegetation index and transformed vegetation index were similar to the ratios and differences. Geenness was also highly correlated with the canopy characteristics, but brightness was not.

Compared to single bands, the use of the transformations, infrared/red, red/infrared, vegetation index, transformed vegetazion index, and

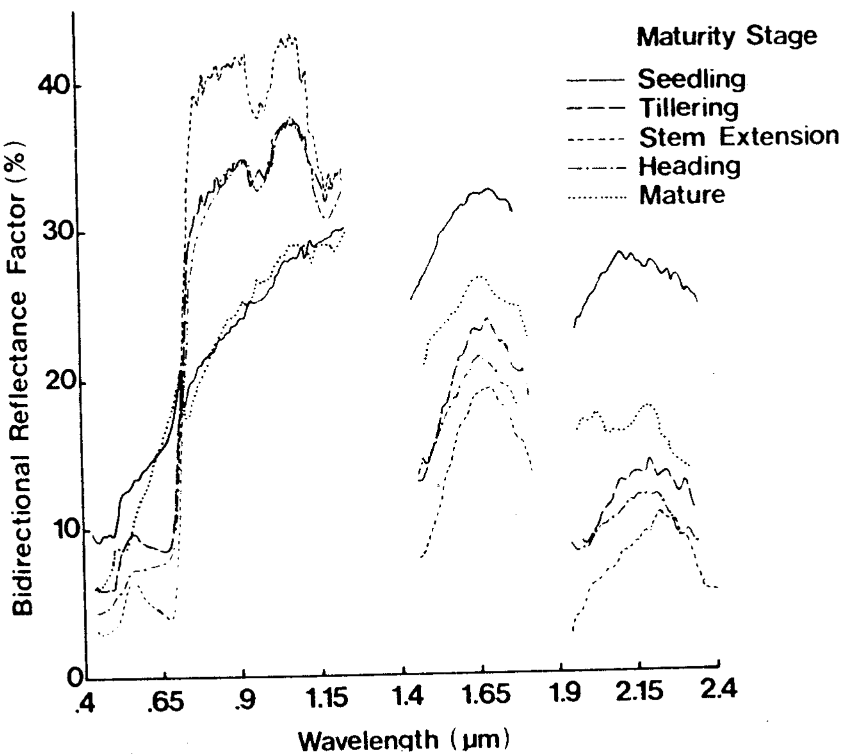

Figure A-6. Spectral reflectance of spring wheat canopies at several maturity stages. Measurements were made at Williston, North Dakota during May-August, 1976 and include plots with different soil moisture levels, planting dates, nitrogen fertilization and cultivars.

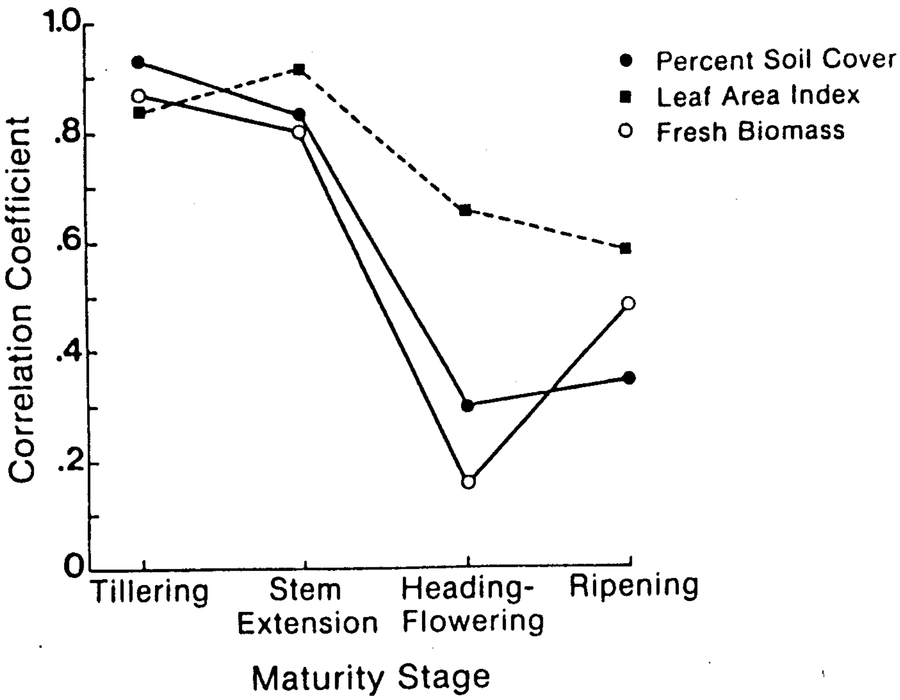

Figure A-7. Effect of maturity stage on the correlation of near infrared reflectance (0.76-0.90 μm band) and agronomic characteristics of spring wheat canopies.

greenness increased the correlation of the spectral data to the canopy variables, although not by a large amount, indicating that they are sensitive to the presence of green vegetation and may have the effect normalizing measurements under varying conditions. However, the various transforms were all found to be highly correlated with each other and it is difficult to determine that any one is superior.

Plant development and maturity (as opposed to growth or increase in size) cause many changes in canopy geometry, moisture content, and pigmentation of leaves which are also manifested in the reflectance characteristics of canopies. Figure A-6 shows the spectra of spring wheat at several different maturity stages. Maturity stage has a strong influence on the relationship of the canopy characteristics and reflectance as shown in Figure A-7. There is a definite decrease in the correlations during the heading-flowering and ripening stages. Leamer et al. (1978) reported a similar decrease after heading in the correlation of spectral response with canopy variables for winter wheat.

Prediction of Canopy Variables

Estimation of canopy variables from multispectral data for use in crop growth and yield models is an important potential application of multispectral remote sensing. Understanding the relation of agronomic properties of crop canopies to reflectance in various regions of the spectrum leads to the development of regression models for estimating canopy variables from measurements in several wavelength bands.

Table A-3 shows results using selections of one to six wavelength bands for prediction of canopy variables. By computing all possible regressions, the best subset of each size was selected considering the amount of variability explained and the bias of the resulting regression equation. The near and middle infrared bands were found to be most important in explaining the variation in canopy variables. For leaf area index and percent soil cover, the 0.76-0.90 μm wavelength band accounts for more of the variation than any other single band. The 2.08-2.35 μm wavelength band is the single most important band in

Table A-3. Selection of combinations of the best 1, 2, . . .6 wavelength bands for estimating percent soil cover, leaf area index, fresh biomass, dry biomass, and plant water content during the seedling thru flowering stages of crop development.

Canopy Variable	No. Bands Entered	R^2	C_p *	Bands Entered (µm) 0.45–0.52	0.52–0.60	0.63–0.69	0.76–0.90	1.55–1.75	2.08–2.35
Percent Soil Cover	1	.86	132				X		
	2	.92	16				X		X
	3	.92	15	X			X		X
	4	.93	4	X	X		X		X
	5	.93	5	X	X	X	X		X
	6	.93	7	X	X	X	X	X	X
Leaf Area Index	1	.84	37				X		
	2	.87	7				X	X	
	3	.88	2				X	X	X
	4	.88	4	X			X	X	X
	5	.88	5	X	X		X	X	X
	6	.88	7	X	X	X	X	X	X
Fresh Biomass	1	.73	239						X
	2	.76	211		X				X
	3	.83	109		X	X			X
	4	.88	41		X	X	X		X
	5	.90	12	X	X	X	X		X
	6	.93	7	X	X	X	X	X	X
Dry Biomass	1	.65	252						X
	2	.67	229	X	X				
	3	.81	78		X	X			X
	4	.84	44		X	X	X		X
	5	.87	20	X	X	X	X		X
	6	.88	7	X	X	X	X	X	X
Plant Water Content	1	.75	201						X
	2	.77	175		X				X
	3	.83	98	X	X		X		
	4	.88	34		X	X	X		X
	5	.90	9	X	X	X	X		X
	6	.90	7	X	X	X	X	X	X

*The regression equation is unbiased when the 'C_p' value is equal to or less than the number of terms in the equation.

explaining the variation in fresh biomass, dry biomass, and plant water. The 2.08-2.35 μm wavelength band is one of the two most important bands in explaining the variation in percent soil cover and one of the three most important bands explaining the variation in leaf area index.

From Table A-3 the difference between the number of bands entered that produce a near maximum R^2 and the number of bands entered where the resulting prediction equation is unbiased can also be examined. An unbiased equation results when the 'C_p' value is equal to or less than the number of terms in the resulting regression equation (Mallows, 1973). For leaf area index and percent soil cover, the near maximum R^2 value is reached after the entry of three out of the six possible thematic mapper bands. However, the 'C_p' values indicate that five bands would have to be used to have an unbiased prediction of leaf area index and four bands would be necessary for percent soil cover.

The agreement between the measured and predicted percent soil cover, leaf area index, and fresh biomass is shown in Figure A-8. Similar results were obtained for the other canopy variables. There are several factors that make a perfect prediction impossible for these data, including: (1) the agronomic measurements of the crop canopy were subject to measurement error, (2) plant maturity stage has an effect on reflectance (for example, a canopy with an LAI of 1.0 early in the season has a different spectral response than a canopy with a similar LAI later in the season), (3) the data that the prediction equations are derived from contains variation induced by the different agronomic treatment levels, and (4) the time of day that the data were collected may have some effect on canopy reflectance. Despite the variation induced by each of these factors, measurements in a small number of wavelength bands in important regions of the spectrum can explain much of the variation in canopy variables and thus, result in satisfactory predictions of canopy variables.

Table A-4 shows the maximum R^2 value obtainable using the Landsat bands, the best four out of the six possible thematic mapper bands, and then all six thematic mapper bands to predict each canopy variable. In

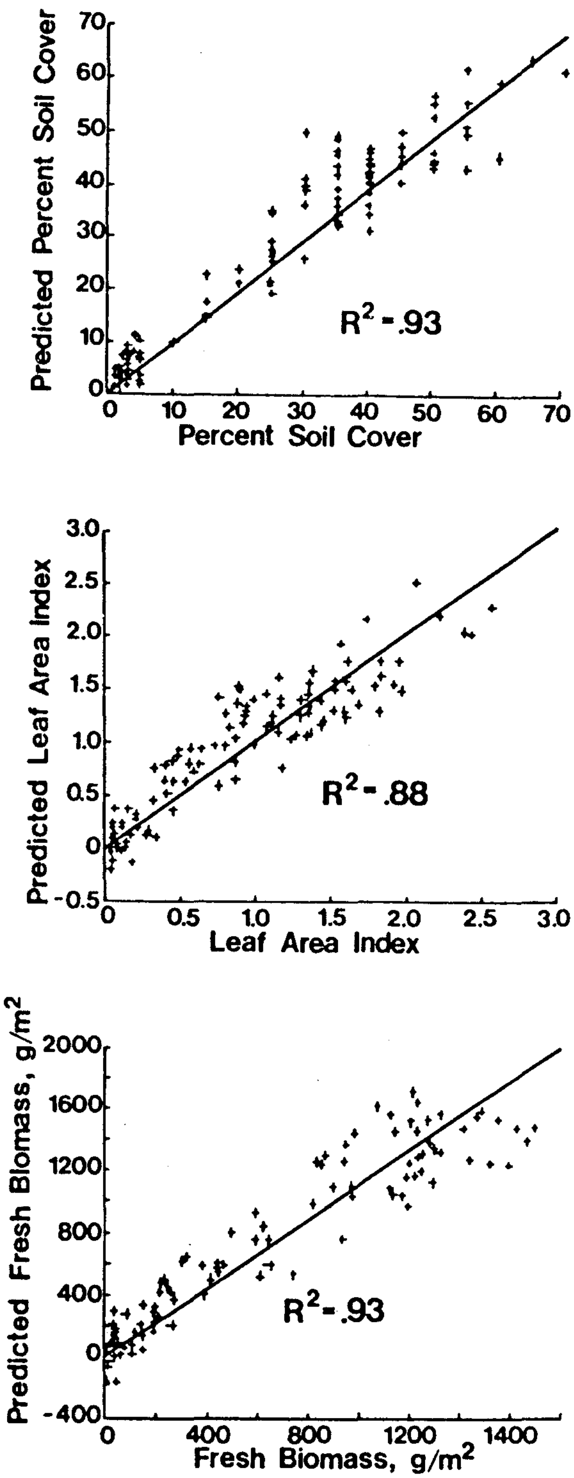

Figure A-8. Comparison of measured and predicted percent soil cover, leaf area index, and fresh biomass of spring wheat canopies.

Table A-4. The R^2 values for predictions of percent soil cover, leaf area index, fresh and dry biomass, and plant water content with four Landsat MSS bands, the best four thematic mapper bands, and the six thematic mapper bands.

Wavelength Bands	Percent Soil Cover	Leaf Area Index	Fresh Biomass	Dry Biomass	Plant Water Content
Landsat MSS Bands	0.91	0.86	0.86	0.84	0.85
Best Four Thematic Mapper Bands*	0.93	0.88	0.88	0.84	0.88
Six Thematic Mapper Bands	0.93	0.88	0.91	0.88	0.90

*See Table A-3.

every case the best four out of six thematic mapper bands explained more of the variation in a canopy variable then the four Landsat MSS bands. Addition of the other two thematic mapper bands resulted in only small increases in the R^2 values.

1.3 Summary and Conclusions

Spectral and agronomic measurements of spring wheat canopies were analyzed to determine the relation of agronomic properties of crop canopies to their spectral reflectance. A strong relationship between spectral response and percent soil cover, leaf area index, biomass and plant water content was found. The relationship, however, is influenced by crop maturity. The best time period for assessing these canopy variables is from the tillering to heading stages of development. Prior to tillering the spectral response is strongly dominated by the soil background and, as the crop begins to ripen, the spectral sensitivity to measures such as leaf area index, biomass, and plant water content decreases.

In each wavelength region, the correlation of the thematic mapper band with crop canopy variables was greater than that of the corresponding Landsat MSS band. Regression equations developed to explain the variation in crop canopy variables showed that the 2.08-2.35 μm wavelength band was the single most important band in explaining the variation in fresh biomass, dry biomass, and plant water content; whereas, the near infrared band (0.76-0.90 μm) explained the most variation in leaf area index and percent soil cover. The results demonstrate the importance of collecting spectral information in the middle infrared wavelength region, as well as the visible and near infrared, for crop assessments.

The R^2 values for comparisons of measured and predicted canopy variables ranged from 0.80 to 0.91 when three or more spectral bands were included, indicating the potential for using remotely sensed spectral measurements to characterize the status of crops. Analyses showed that the best four thematic mapper bands could estimate crop canopy variables better than the four Landsat bands. The difference is attributed to the narrower and more optimum placement of the thematic mapper bands in relation to the spectral characteristics of vegetation.

The strong relationship between spectral reflectance and different crop canopy variables illustrates the potential to monitor crop growth and predict yield. Future research needs to investigate the amount of variation induced by different agronomic treatment factors on spectral reflectance and whether important treatment factors are spectrally separable. The type of prediction equations developed in this investigation need to be extended to several years of data, then used to estimate independent data sets.

1.4 References

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2. EFFECTS OF CULTURAL AND ENVIRONMENTAL FACTORS ON THE REFLECTANCE CHARACTERISTICS OF SPRING WHEAT CANOPIES

The crop canopy is a dynamic entity influenced by many cultural and environmental factors. Therefore, it is important to quantify and understand the sources of variation in spectral measurements of crops. Some of the variation may be associated with important agronomic factors which it may be desirable to inventory or monitor (for example, dryland vs. irrigated wheat). On the other hand it is also important to know the magnitude of variation associated with a factor such as cultivar which we would most likely not want to identify or monitor.

Examples of spectra acquired in 1976 at the Williston, North Dakota, Agriculture Experiment Station are shown in Figure A-9 to illustrate some of the effects of agronomic treatments on the spectral response of spring wheat. Further experiments using an improved experimental design were conducted in 1977 to determine the effects of the various agronomic treatments (soil moisture availability, planting date, nitrogen fertilization, and cultivar) on the reflectance of spring wheat canopies. The results of the 1977 investigation are reported in this section.

2.1 Experimental Approach

Data were collected at the Williston, North Dakota Agriculture Experiment Station during the summer of 1977. The Experiment Station is locate[d] in the gently rolling uplands above the Missouri River Valley and is representative of dryland farms of the region. The average annual precipitation of 36 cm is just adequate for successful farming operations in normal years. The area is semi-arid and humidity remains low throughout the year.

The soil in the study area is a Williams loam (Typic Argiustoll) which was developed in glacial till. The A_1 surface horizon is dark brown (10YR 3/2) when moist, but very light (10YR 4/3) in color when dry. The predominant crop grown in the northwest area of the state is hard red

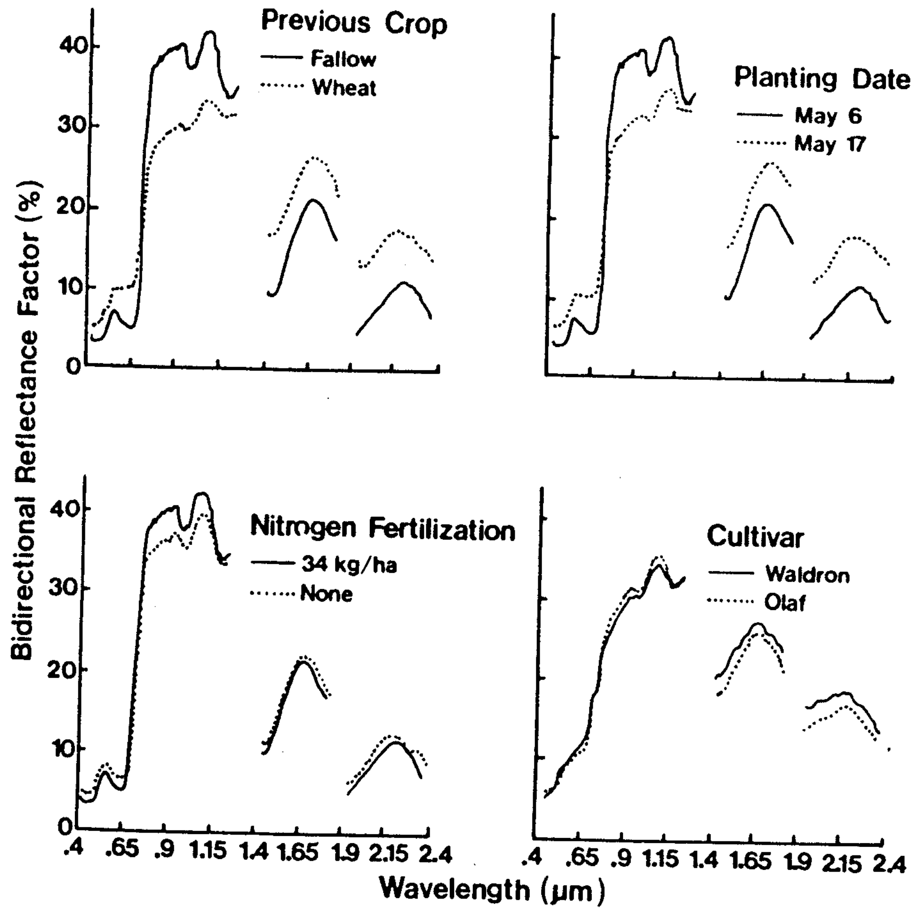

Figure A-9. Effects of agronomic treatments on the spectral reflectance of spring wheat. Spectra were measured on June 18, 1976, during the stem extension stage of development, except for the spectra of cultivars which were measured on July 16 after heading.

spring wheat. Because of the limited amount of rainfall, the majority of land is planted to crops every other year and is left fallow in intermediate years to allow subsoil moisture to accumulate.

The spring wheat experiment under investigation was a split plot design. Within each available soil moisture condition (whole plot), there were two replications of a factorial design with cultivar, nitrogen fertilization, and planting date as experimental treatments:

Available Soil Moisture
- Low (wheat crop in 1976)
- High (fallow in 1976)

Planting Date
- Early (May 9, 1977)
- Late (May 23, 1977)

Cultivar
- Semi-dwarf (Olaf)
- Standard (Waldron)

Nitrogen Fertilization
- None
- 44 kg/ha

Spectral measurements were made with an Exotech Model 100 Radiometer in four wavelength bands (0.5-0.6, 0.6-0.7, 0.7-0.8, and 0.8-1.1 μm). Measurements in all bands were taken instantaneously and recorded by a hard copy data logger. A boom mounted on a van supported the radiometer at 3.5 m above the canopies and 3.5 m away from the van. At this elevation and with a 15^{o} field of view the sensor viewed a 0.9 m diameter ground area. The reflectance of all 32 plots was measured at approximately hourly intervals during the middle part of the day when the sun angle was greater than 45^{o}.

A 1.2 m square standard painted with highly reflecting barium sulfate was used as a basis for the bidirectional reflectance factor calibration. The reflectance standard provided a field calibration reference with stable, known reflectance properties. A dark level response of the instrument was also obtained by holding an opaque, lighttight apparatus against the instrument's entrance ports to measure the internal system noise or deviation from zero. The response of the calibration panel was measured approximately every 15 minutes during data collection over the plots and the dark level every 30 minutes. These values were then used in the following equation to calibrate readings taken over the plots:

$$BRF(\lambda) = \frac{Ds(\lambda) - ds(\lambda)}{Dr(\lambda) - dr(\lambda)} \cdot Rr(\lambda)$$

Where, $BRF(\lambda)$ = bidirectional reflectance factor (%) at a specific wavelength interval (λ),

$Ds(\lambda)$ = response of instrument to scene (plot),

$ds(\lambda)$ = dark level response of instrument taken closest in time to scene,

$Dr(\lambda)$ = response of instrument to painted barium sulfate reference standard,

$dr(\lambda)$ = dark level response of instrument taken closest in time to reference standard measurement, and

$Rr(\lambda)$ = reflectance of painted barium sulfate reference standard (measurement in laboratory by comparison with pressed barium sulfate).

The plots were planted in 17.8 cm (seven inch) rows and were rectangular in shape (3.5 x 15.3 m). Leaf area index, fresh and dry biomass, growth stage, plant height, number of leaves per plant, percent of green, yellow and brown leaves were measured on a one meter row sample from each plot on each day that reflectance measurements were made. In addition to the daily meteorological records kept by the Experiment Station, a compact weather station was set up each day that spectral data were collected. Meteorological measurements including air temperature, barometric pressure, relative humidity, wind speed and direction, and total irradiance were recorded continuously through the day on strip charts.

The objective of the data analysis was to determine the significance of the agronomic treatments for each of the dates (crop maturity stages) and wavelength bands. Since previous work (Crecelius, 1978) has indicated that there is some diurnal variation in the spectral reflectance of wheat canopies, a covariance analysis was used to adjust the treatment means of the reflectance variables to be estimates of what they would be if all plots were measured at the same time (Steel and Torrie, 1960). A separate covariance analysis was run for each date and wavelength band with time and $time^2$ as covariates to adjust for the two components of diurnal variation which are symmetric and asymmetric about solar noon (Crecelius, 1978).

2.2 Results and Discussion

Initial analysis of the data indicated that the whole plot error (between soil moisture levels) was consistently larger than the split plot error for each date and band analyzed. It was determined that the replications in this experiment were not a result of random selection but described a location within the whole plot. Thus, differences due to available soil moisture could not be tested statistically.

A summary of the significant results based on the covariance analysis is presented in Table A-5 for each date and wavelength band. The effects indicated there had a significant (α=.01) effect on spectral response after adjusting for the symmetric and asymmetric components of time. Planting date was generally significant for all dates and at all wavelengths. Although no statistical test for the main effect of soil moisture level was available, significant interactions of other factors with soil moisture provided indications of its significance. An additional method of ascertaining the overall importance of the experimental treatments is to consider the percentage of total variability accounted for by each treatment (Table A-5). This approach permits an evaluation of the effect of available soil moisture.

On June 1, planting date is the primary factor affecting spectral response (Table A-5). With a 14 day difference between the early and late planting dates there are differences in the agronomic, as well as spectral, characteristics of the wheat canopies (Table A-6). The wheat

Table A-5. Percent of total variation in reflectances, greenness and brightness accounted for by soil moisture level and significant agronomic factors and interactions.[1]

Mission Date	Treatment Effect[2]	Wavelength Band (μm) .5-.6	.6-.7	.7-.8	.8-1.1	Transformations Greenness	Brightness
June 1	M	4.7	3.6	9.4	8.3	4.6	8.2
	P	58.6	34.4	81.9	83.5	42.1	79.2
	MP	5.4	8.4	-	-	10.1	0.5
	CNP	-	-	0.3	-	-	-
	MNP	-	-	0.3	-	-	-
	MCP	-	-	0.2	-	-	-
	MCN	0.9	-	-	-	-	-
June 18	M	5.7	5.9	0.2	0.9	3.9	0.1
	N	2.5	-	-	-	-	-
	P	19.3	22.7	26.9	41.5	47.9	14.6
	MN	-	-	3.2	3.6	-	2.2
	MP	39.0	32.7	3.2	-	11.6	10.1
	MNP	3.3	3.3	-	-	-	-
July 14	M	52.4	60.5	9.2	53.4	61.4	0.0
	C	1.2	1.0	-	3.0	2.1	-
	N	1.9	1.6	5.5	5.5	3.8	-
	P	6.5	4.1	-	4.7	6.1	-
	MP	5.3	6.0	12.4	-	0.8	21.1
	MCNP	-	-	-	2.2	1.1	-
July 20	M	64.6	51.9	6.9	34.7	62.8	15.0
	C	-	-	-	-	2.8	-
	N	-	-	-	-	3.1	-
	P	-	26.7	-	-	21.0	-
	MP	5.5	-	25.2	-	-	-
August 5	M	61.8	53.4	33.9	4.7	58.2	40.8
	C	5.7	12.1	-	-	3.4	-
	N	-	-	-	-	3.1	-
	P	5.7	12.1	-	-	12.3	5.3
	MP	0.3	-	-	7.5	-	-

[1] Total variation is considered that due to treatments, diurnal variation, and experimental error.

[2] M, available soil moisture; P, planting date; N, nitrogen fertilization; C, cultivar.

Table A-6. Mean agronomic characteristics of spring wheat canopies by soil moisture level and planting date (Williston, North Dakota, 1977).

Measurement Date	Soil Moisture Level	Planting Date	Maturity Stage	Plant Height	Soil Cover	Leaf Area Index	Fresh Biomass	Dry Biomass	Plant Water Content
				cm	%		g/m^2	g/m^2	g/m^2
June 1	High	Early	2.1	14	7	0.2	72	8	64
		Late	1.0	9	2	0.1	32	1	31
	Low	Early	2.1	13	6	0.3	50	7	43
		Late	1.0	9	2	0.2	37	3	34
June 18	High	Early	2.4	29	47	1.7	769	105	664
		Late	2.2	23	23	0.7	335	30	306
	Low	Early	2.4	24	20	0.8	407	50	358
		Late	2.2	23	22	0.7	315	29	285
July 14	High	Early	4.7	64	52	1.3	1528	620	908
		Late	4.4	58	60	2.1	1709	480	1229
	Low	Early	4.7	46	42	0.5	723	285	438
		Late	4.6	46	49	0.8	715	215	500
July 20	High	Early	4.8	67	50	0.7	1525	603	922
		Late	4.7	68	51	1.2	1454	476	978
	Low	Early	5.1	45	38	0.2	781	307	480
		Late	4.8	48	44	0.5	694	224	470
August 5	High	Early	5.3	65	46	0.0	672	466	206
		Late	5.2	66	46	0.1	1117	550	567
	Low	Early	5.3	46	30	0.0	439	237	202
		Late	5.2	45	35	0.0	567	259	308

planted at the later planting date (May 23) is at the seedling stage of maturity, while the early planted wheat (May 9 planting date) is beginning to tiller. The differences in spectral response are attributed to the differences in percent soil cover, leaf area index, and biomass. Planting date continues to be the primary agronomic factor affecting reflectance on June 18 during the later phases of tillering.

By July 14 differences in vegetative growth and spectral response due to planting date are reduced as the later planted wheat, growing at a faster rate due to warmer temperatures and longer days during its early stages of development than the early planted wheat, is nearly the same size as the early planted wheat. At this time, heading to flowering stages of maturity, soil moisture availability is the major factor affecting the growth and development (Table A-6) and spectral response (Table A-5) of the wheat canopies. Although there are significant differences due to cultivar and nitrogen fertilization, they are small compared to those associated with available soil moisture.

A week later, on July 20, soil moisture level is the most important factor accounting for differences in spectral response (Table A-5). Effects due to cultivar and fertilization are not significant except in greenness.

On August 5, as the canopies are ripening, soil moisture level continues to be the primary factor influencing the spectral response. Since the canopies have similar maturity stages, the differences in spectral response are attributed to the differences in percent soil cover and biomass (Table A-6).

2.3 Summary and Conclusions

The effects of four agronomic treatments (soil moisture, planting date, nitrogen fertilization, and cultivar) on the reflectance of spring wheat canopies was investigated. Early in the growing season planting date is the primary agronomic factor influencing the reflectance of spring wheat.

The spectral differences are primarily due to differences in the amount of vegetation present. Later in the season at the heading to ripening stages, the level of soil moisture becomes the most important factor. Wheat grown on land with higher levels of available soil moisture had a greater percent soil cover, leaf area index, and biomass causing increased near infrared and reduced visible reflectance. In these experiments cultivar and nitrogen fertilization had relatively little effect on the spectral response of spring wheat. Again, examination of the agronomic data shows that these two treatments had little influence on the growth and development of the spring wheat canopies. The primary difference in the two cultivars was in plant height, rather than in leaf area or biomass. And, since the soils of this area of North Dakota are relatively high in nitrogen supplying capacity, the addition of nitrogen fertilizer had only minor effects of the growth of wheat.

2.4 References

Crecelius, D.W. 1978. The time of day effect on the reflectance of spring wheat canopies in the four Landsat MSS bands. Unpublished M.S. Thesis. Department of Agronomy, Purdue University, West Lafayette, Indiana.

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3. ASSESSMENT OF CROP DISCRIMINABILITY AS A FUNCTION OF CROP MATURITY STAGE AND WAVELENGTH BAND SELECTION

The application of remote sensing to crop inventories relies upon the ability to detect and identify the crops of interest from the spectral data. Unless correct crop identification can be consistently made, the goal of accurately predicting crop acreage and production cannot be achieved.

The overall objective of these analyses was to assess the potential for crop discrimination. The specific objectives were: (1) to determine which cover types may be confused, (2) to determine at what growth stages separability is maximized, and (3) to determine which regions of the spectrum are best for crop discriminability.

3.1 Experimental Approach

LACIE Field Measurements data acquired by the helicopter spectrometer over the intensive test sites at Finney County, Kansas, in 1975 and Williams County, North Dakota, in 1976 were analyzed. These data are well-suited for this investigation because of the frequent measurements made in narrow wavelength bands and the associated ground truth observations. Spectral data were analyzed using the Landsat MSS and proposed thematic mapper wavelength bands, as well as the greenness and brightness transformations of reflectance.

Spectral plots of the data were made in two ways: (1) several crops on the same measurement date and (2) a single crop over several dates. The plots gave qualitative indications of what crops may be separable at any given time and also show changes in a crop over the growing season. An extensive set of example plots can be found in the report entitled, "Crop Spectra from LACIE Field Measurements," (Hixson et al., 1978).

Analysis of variance and range tests were used to determine dates and wavelength bands where significant differences in spectral response occurred. Unitemporal and multitemporal multivariate discriminant analyses were performed to investigate crop discriminability. Percent correct classification and percent commission errors were computed.

3.2 Results and Discussion

Williams County, North Dakota

In general, 98 percent of wheat spectra were correctly classified in the June 26 and later data for both the Landsat MSS and thematic mapper bands (Table A-7). On the first three dates, the percent of wheat spectra correctly identified was generally above 80. Spectra of fallow fields were almost equally well identified on most dates with both Landsat MSS and thematic mapper bands. Fifty percent of the spectra of pasture were confused with fallow after July 20 when using Landsat MSS bands, but substantially less confusion occurred when using the thematic mapper bands.

There was some variation in the percent of wheat spectra correctly classified based on the size of the training set. The results presented in Table A-7 are based on using all available spectra for training. Using a random sample of either 50 or 25 percent of spectra produced very similar results, almost identical on June 25 and later dates.

Although the amount of training used did not significantly alter the percent correct classification achieved, the training method used did have some effect. Figure A-10 presents results obtained from sampling about 50 percent of the spectra using sampling of fields rather than sampling of individual spectra. The percent of wheat correctly identified, particularly in the Landsat MSS bands, was decreased from that obtained using 50 percent of the spectra randomly sampled.

When cumulative spectral information from several dates was used, higher classification accuracies were achieved. The percentage of wheat spectra correctly classified ranged from 97 to 100 for both Landsat and thematic mapper bands. The confusion of pasture with other cover types was not encountered for either Landsat MSS or thematic mapper bands.

Table A-7. Percent correct classification of spring wheat, fallow, and pasture using unitemporal information (Williams Co. ITS, 1976).

Mission Date	Landsat MSS Bands			Thematic Mapper Bands		
	Wheat	Pasture	Fallow	Wheat	Pasture	Fallow
May 13	96.3	90.6	96.7	95.7	96.6	96.7
May 28	76.4	81.7	64.4	84.2	85.9	72.8
June 17	90.5	60.0	93.9	96.4	83.3	91.7
June 25	98.8	73.1	96.2	99.6	82.8	95.7
July 6	98.1	84.0	99.4	98.9	93.3	99.1
July 20	99.6	48.1	98.9	99.6	88.0	98.9
July 28	99.2	38.1	97.0	98.8	85.8	98.3
August 9	97.0	96.4	99.0	98.0	100.0	99.2
August 19	98.0	57.6	96.6	98.4	98.0	98.8

Table A-8. Percent correct classification of spring wheat, fallow, and pasture using the Landsat MSS bands and multitemporal information (Williams Co. ITS, 1976).

Combination of Mission Dates	Wheat	Pasture	Fallow
6/17, 7/6, 7/28	99.3	92.2	99.4
5/28, 6/25, 7/28	98.8	88.0	98.8
5/28, 6/25, 7/20, 8/9	99.5	100.0	99.4
6/17, 6/25, 7/6, 7/28	100.0	95.6	100.0

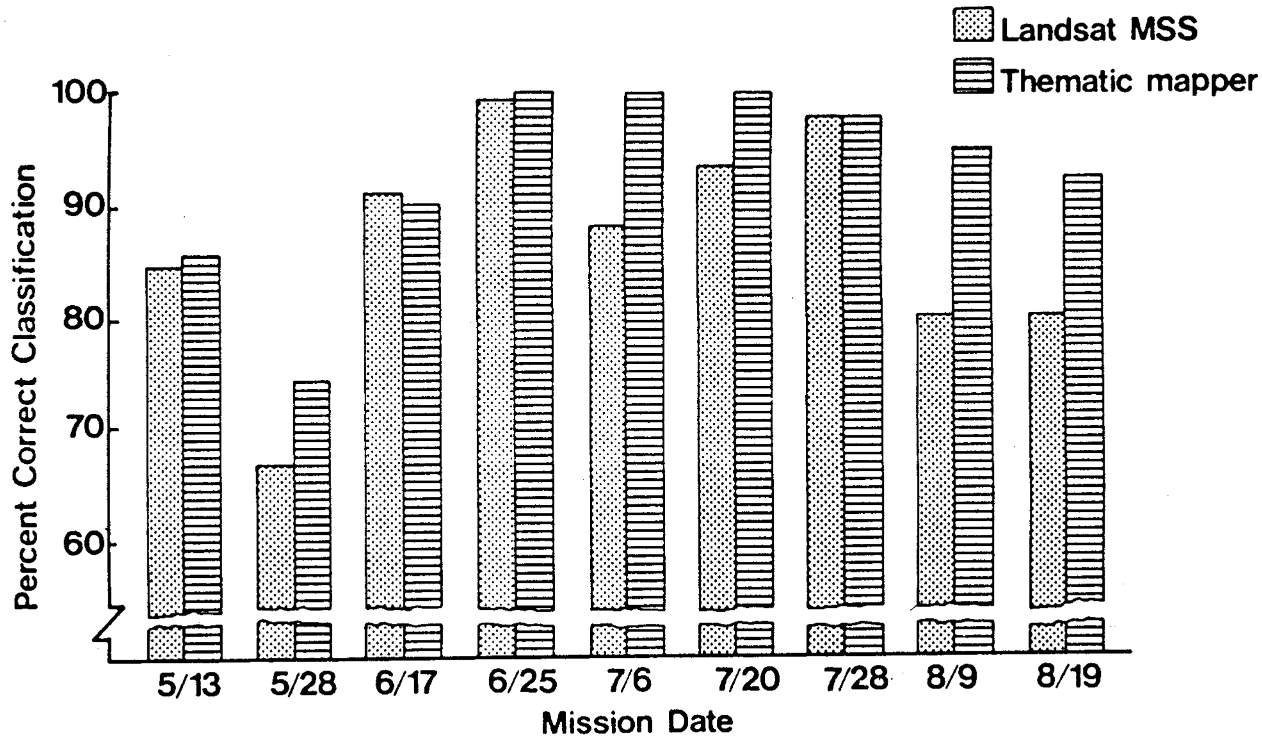

Figure A-10. Comparison of Landsat MSS and thematic mapper spectral bands for spring wheat identification (Williams County, North Dakota, 1976).

An investigation was then carried out to find a reduced set of dates which, when combined, would give results comparable to using the full data set. The combinations of dates used were selected to include information from several important growth stages. Again, using multitemporal information, the confusion of pasture with other cover types was not encountered and all cover types were identified with high accuracy (Table A-8).

Similar unitemporal analyses using the brightness and greenness components of reflectance were also conducted. The results of these analyses did not show an improvement in classification of wheat spectra over the use of two Landsat MSS bands.

Finney County, Kansas

Univariate analyses of variance showed that for every wavelength band and for every date except (.7-.8 μm on June 17), there was a significant difference in reflectance due to crop type. All data were used for training and evaluation of the classification. The results are shown in Table A- 9 .

It appears that wheat and alfalfa can be well distinguished in November. Some confusion exists between these cover types and fallow, perhaps due to the small proportion of soil cover or insufficient statistics to define the spectral distribution of fallow.

In March and April, most wheat has reached a stage of greenness where it can be differentiated from fallow and these cover types remain separable on all following measurement dates. A few wheat fields are still being missed, but almost no fields are being falsely identified as wheat.

On May 14, alfalfa and wheat are distinctly differentiable and remain so on all following measurement dates. Corn, however, has not yet reached a growth stage where it is separable from fallow land. Corn and fallow become spectrally separable by May 21 and then remain so. Beginning on June 8, sorghum can be correctly identified with the exception of some fallow land being classified as sorghum. Fallow, which consists of bare soil

Table A-9. Summary of the separability of cover types at several times during the 1974-75 growing season for the Finney County, Kansas, intensive test site.

Mission Date	Classes	Overall Percent Correct Identification: Landsat MSS	Overall Percent Correct Identification: Thematic Mapper	Comments
Nov. 5	wheat, alfalfa, fallow, other	77	76	Some wheat was classi- as alfalfa and fallow
March 20	wheat, alfalfa, fallow	87	88	Some wheat was missed.
April 8	wheat, alfalfa, fallow	88	87	
May 14	wheat, corn, fallow, alfalfa, other	77	76	Major problem is being classified as another cover type.
May 21	wheat, corn, fallow,	89	90	Same as May 14.
June 2	wheat, corn, fallow, alfalfa, sorghum, other	75	79	Wheat and alfalfa correctly identified. All other cover types are confused.
June 9	wheat, corn, fallow, alfalfa, sorghum, other	67	88	Wheat and sorghum correctly identified by the Landsat bands; alfalfa was also correct with thematic mapper.
June 17	wheat, corn, fallow, alfalfa, sorghum, other	78	83	All crops are separable from fallow; wheat and alfalfa separable; other crops confused.
June 26	wheat, corn, fallow,	88	90	Same as June 17.
July 6	wheat, corn, fallow, alfalfa, sorghum, other	84	92	Same as June 17 except more confusion of sorghum and fallow.

and several degrees of stubble, is confused with other crop types early in the season.

On June 9 and July 6, there is a noticeable difference in crop discriminability between performance of the Landsat MSS and proposed thematic mapper bands with accuracies of thematic mapper bands being higher.

3.3 Summary and Conclusions

Discriminant analyses of crop discriminability were conducted using FSS data with simulated Landsat MSS and thematic mapper wavelength bands. The analyses included data from the Williams County, North Dakota, and Finney County, Kansas, intensive test sites.

Spring wheat in North Dakota was confused with pasture by the Landsat MSS bands when only single date information was used. If multitemporal information was used, however, the two cover types were separable. Training method was found to have a greater effect on classification results than amount of training. Insufficient data were acquired at the test site for quantitative analyses describing the separability of wheat from other small grains.

Winter wheat in Kansas was occasionally confused with alfalfa and was confused with fallow land early in the season before sufficient soil cover had been reached for the wheat to appear characteristically green. Corn and sorghum could not be identified until much later in the season due to their late planting date.

Classification performance for the thematic mapper bands was somewhat higher than for the Landsat MSS bands. Use of the brightness and greenness components of reflectance did not show an improvement in classification of wheat spectra over the use of two Landsat bands.

3.4 References

Hixson, M.M., M.E. Bauer, and L.L. Biehl, 1978. Crop Spectra from LACIE Field Measurements. LACIE-00469, JSC-13734, and LARS Contract Report 011578.

B. Field Measurements Data Management*

The development of the field research data library at Purdue/LARS was initiated in the fall of 1974 by NASA/Johnson Space Center (JSC) with the cooperation of the United States Department of Agriculture (USDA) as a part of the Large Area Crop Inventory Experiment (LACIE). The purpose for developing the data base is to provide fully annotated and calibrated multitemporal sets of spectral, agronomic, and meteorological data for agricultural remote sensing researchers. Spectral, agronomic, and meteorological measurements over primarily wheat have been made on three LACIE test sites in Kansas, North Dakota, and South Dakota for three years. During this past year the data library was expanded to include data collected for corn and soybean experiments in Indiana.

Milestones reached during this year have been: (1) completion of the 1976-77 data processing, (2) development of graphical and statistical analysis software, (3) development of documented data processing software, and (4) distribution of data to researchers representing university, government and commercial research organizations.

A report entitled "Crop Spectra from LACIE Field Measurements" was prepared and distributed this part year. This document contains examples of the spectrometer data in the form of spectral reflectance curves illustrating the major sources of spectral variation of wheat and related crops. The examples include variations in wheat spectra due to differences in maturity, biomass, soil color, and soil moisture, as well as comparisons of spectra of wheat and other crops.

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*This section describing the results of Task 1B, Field Measurements Data Management, was prepared by the task leader, Larry Biehl. The contributions of Jeanne Etheridge, Cathy Kozlowski, Jerry Majkowski, and Jeff McMeekin to the data processing and analysis software development and Cathy Axtell and staff of the LARS Computer Facility for data preparation are gratefully acknowledged.

1. FIELD RESEARCH DATA LIBRARY AND DISTRIBUTION

The general organization of the field research data library is illustrated in Figure B-1. The data in the library includes spectral measurements (multispectral scanner and spectrometer), agronomic measurements, meteorological measurements, photography, mission logs and data verification reports. The data formats available to researchers are digital tape, film, and data listings.

The instruments used to collect spectral data are of two types, multispectral scanners and spectrometers/radiometers. The multispectral scanners include the 4-channel Landsat MSS, the 11-channel MMS on the NASA-P3 aircraft, and the 24-channel MSS on the NASA-C130 aircraft. The spectrometers include the NASA/ERL Exotech 20D field system, the NASA/JSC Field Spectra Acquisition System (FSAS), the NASA/JSC Field Spectrometer System (FSS), the Purdue/LARS Exotech 20C field system. The radiometer includes the Purdue/LARS Exotech 100 field system.

The spectrometer data are processed into a comparable format (spectral bidirectional reflectance factor) in order to make meaningful comparisons of the data acquired by the different sensors at different times and locations. The spectrometer tapes contain the spectral bidirectional reflectance factor measurements along with most of the corresponding agronomic and meteorological measurements. The data is stored on the tape in LARS spectrometer data storage tape format.

The multispectral scanner data stored on the LARSYS Version 3 formatted tapes are approximately linearly related to scene radiance. The information is available for the researcher to calibrate the scanner data to in-band bidirectional reflectance factor if he wants to. Some of the multispectral scanner data is available in universal format.

In the past twelve months, 45 aircraft scanner runs and 30,000 spectrometer runs have been processed and made available in the field

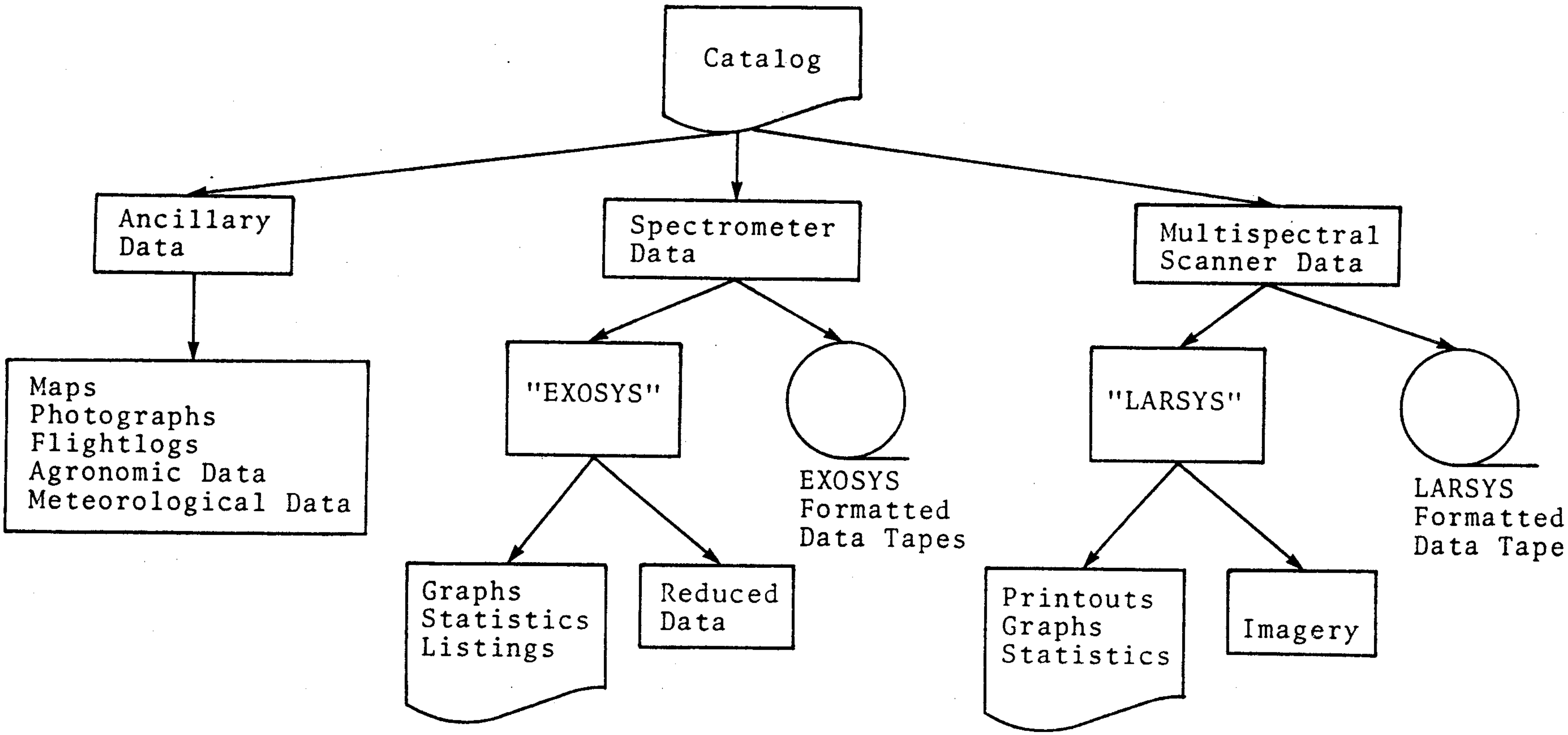

Figure B-1. Organization of Field Research Data Library. EXOSYS and LARSYS are Purdue/LARS software systems to analyze spectrometer and multispectral scanner data.

research data library. The status of data processing is summarized in Tables B-1 and B-2. Processing of the remaining 1976-77 crop year data, along with the sun angle-view angle-view direction data, was completed earlier this year. Processing of the 1977-78 data was begun this fall.

The Field Research Data Library Catalog summarizes the data available. The catalog is divided into separate volumes - one for each crop year during which data were collected. Volume III, 1976-77, of the catalog was updated this past year. Discussions with the past and present users of the catalog and data have provided direction for future updates of the catalog.

Six institutions, representing university, government, and commercial research organizations, have requested and received the LACIE field research data this year. In addition all the data are routinely available to researchers at Purdue/LARS and investigators at NASA/Johnson Space Center have direct access to the digital data via the remote terminal to the LARS' computer located there.

Another organization inquired about specialized processing of some of the aircraft scanner data into thematic mapper resolution, but did not formally request it. Table B-3 summarizes the data distribution during the past year.

Table B-1. Summary of LACIE Field Measurements data in the Field Research Library by year, instrument, and data type.

Instrument/Data Type	Crop Year 1975	1976	1977
Landsat MSS			
Whole Frame CCT (Frames)	20	62	34
Aircraft Scanner (Dates/Runs)	19/149	16/97	7/35
Helicopter Mounted Field Spectrometer (Dates/Runs)			
Field Averages	19/2,343	27/2,193	21/1873
Individual Scans	19,29,579	27/38,476	21/34,060
Truck Mounted Field Spectrometer (Dates/Runs)			
FSAS	6/65	23/322	16/426
Exotech 20C	24/1599	18/2542	21/1075
Exotech 20D	45/645	----	----

Table B-2. Status of Preparation of 1977-78 Multicrop Supporting Field Research Data.

Sensor System/Data Type	Completed & In Library	In Processing	At JSC
	Dates/Observations		
Landsat MSS			
Whole Frame CCTS	2	0	- - -*
Aircraft Scanner	3/15	1/5	- - -
Helicopter-Mounted Field Spectrometer			
Field Average Data	0	6/	2/
Individual Scans	0	6/	2/
Truck Mounted Field Spectrometer	2/58	22/1097	- - -

*The 1978 Landsat tapes for the Hand County site are in processing at GSFC.

Table B-3. Recipients of Field Research data during 1977-78.

Institution	Data Requested and Received
Enviromental Research Institute of Michigan (ERIM)	Spectrometer data tapes, ground photos, flight logs, field maps.
Texas A&M University, Remote Sensing Center	Spectrometer data tapes, ground photos flight logs, field maps
NASA, Goddard Space Flight Center	Spectrometer data tapes, Landsat MSS data tapes, aerial photography, ground photos, field maps.
General Electric Corporation (contract with NASA/GSFC)	Spectrometer data tapes, agronomic and meteorological measurements, field maps, ground photos, aerial photography.
General Electric Corporation	Landsat MSS data tapes, agronomic measurements, Landsat color composite imagery.
USDA, Agriculture Research Service, Weslaco, Texas	Helicopter (FSS) photography, agronomic measurements, meteorological measurements, field maps.
University of South Florida, Department of Mathematics	Spectrometer data tapes.

2. DEVELOPMENT OF GRAPHICS, STATISTICS AND DATA PROCESSING SOFTWARE

During the LACIE Field Measurements Project over 100,000 observations of spectrometer data were collected. Additional observations were collected this year in preparation for multicrop studies. These increasingly large numbers of field measurements type observations have brought about a need for more powerful research tools to verify and analyze the data efficiently and effectively. During this past year, several new analysis software tools were developed and implemented on the Purdue/LARS IBM 370/148 computer. These include new graphics capabilities and additional statistical capabilities (such as clustering) for spectrometer data. Also, an updated version of SPSS (Statistical Package for the Social Sciences) having additional statistical analysis capabilities was obtained and made available to researchers on the Purdue/LARS computer.

The software system implemented on the Purdue/LARS computer to access the spectrometer data and associated agronomic and meteorological measurements stored on tape is called EXOSYS. The version which contains the new graphics and statistics capabilities is termed EXOSYSDV. The new analysis tools for researchers include capabilities to:

- Review spectrometer data quickly on a CRT terminal.
- Plot data on high resolution Varian printer/plotter in addition to line printer.
- Plot,print or punch numerical agronomic and meteorological data stored on tape.
- Fit polynomial curves of one to ten degrees to data and print regression coefficients and correlation coefficiants.
- Apply arithmetic transformations to data.
- Cluster spectrometer data with one to 30 user specified bands and print tables with summaries of results.

For the graphical software routines, EXOSYSDV makes use of the Graphics Compatibility System (GCS) acquired from the U.S. Army Corps of Engineers at the Waterways Experiment Station, Vicksburg, Mississippi. There was no cost for acquiring the GCS software package except for postage. The package of GCS software routines is very extensive for graphical purposes; the use of the GCS software routines to do the graphical plotting instead of writing completely new software reduced the implementation time for the above mentioned tools from years to months. Examples of some of the graphical output are illustrated in Figures B-2 through B-5. Other graphical options available to the researcher using EXOSYSDV include polar coordinate system graphs, natural logarithmic and common logarithmic (base ten) formatted graphs, spline curve fitting, and other scaling and axes variations.

The clustering capability implemented in EXOYSDV is the same cluster algorithm used in LARSYS (unsupervised with Euclidean distance measure) except that the initial cluster centers are placed along the principal eigenvector. Examples of some of the new statistical output from EXOSYSDV are illustrated in Figures B-6 through B-8. Also the spectral information and some of the agronomic measurements stored on the spectrometer tapes can be punched and used in other statistical analysis packages such as SPSS or in user written Fortran programs.

Documentation of the new capabilities in EXOSYSDV is the next step to be developed to made the system more useful to researchers both at Purdue/LARS and to researchers at LARS' remote computer terminal sites. Initial development of documentation was completed this past year. In October, a group of LARS researchers presented, in a one day session, an overview of EXOSYSDV to personnel at NASA/JSC and demonstrated to several individuals the use of the system on the Purdue/LARS remote terminals at JSC. Development of new analysis tools and documentation will continue so that researchers are able to make the fullest use of the data in the field research data library.

In addition to the graphics and statistics software additions, the software for processing spectrometer data has been improved. The software for reformatting the Exotech 20C data was revised to make it more efficient, saving both computer and personnel time. The original reformatting system was designed to handle a few hundred measurements per year, compared to 2,000 to 3,000 observations currently collected each year. At the same time additional items of agronomic and measurement data were added to the header record. Capabilities for updating the spectrometer data tapes have been added and documentation describing the reformatting systems written. The documentation will be very helpful in training new personnel how to use the systems.

The design of the software system to process Exotech 100 radiometer and associated measurement and agronomic data was completed. Programming will be completed next year. This system will be a forerunner to the reformatting system for the new multiband radiometer data (see Section C.2).

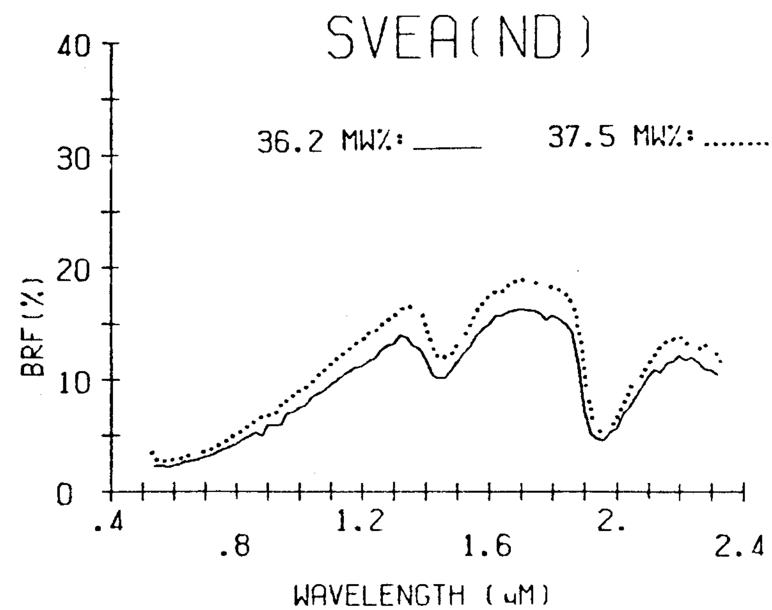

Figure B-2. Example graph from EXOSYSDV of spectral response as a function of wavelength.

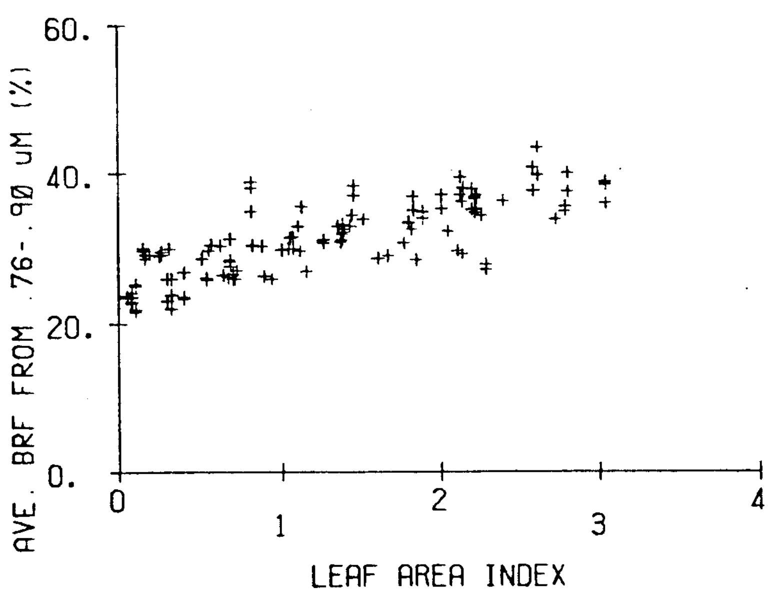

Figure B-3. Example plot from EXOSYSDV of average spectral response for a user selected wavelength band versus an agronomic measurement using EXOSYSDV.

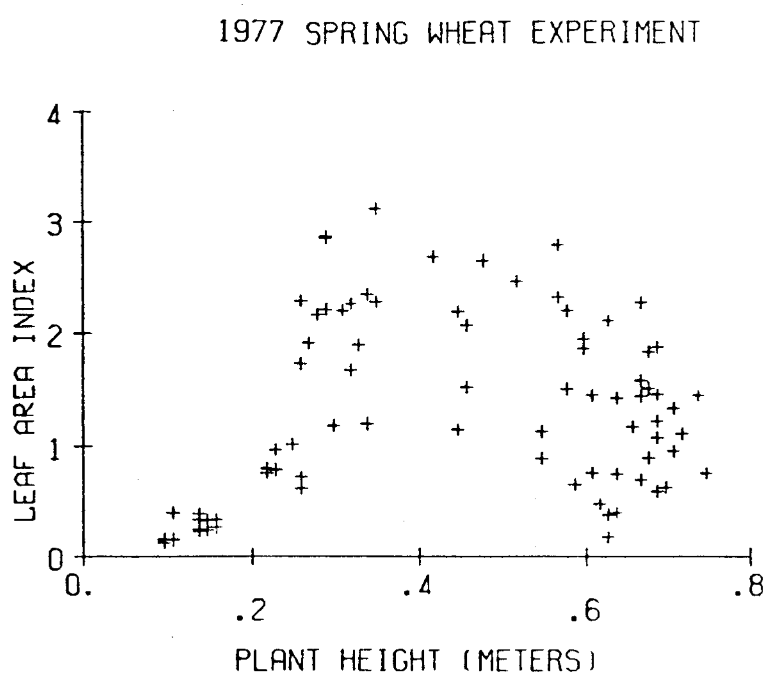

Figure B-4. Example of one agronomic variable plotted against a second agronomic variable using EXOSYSDV.

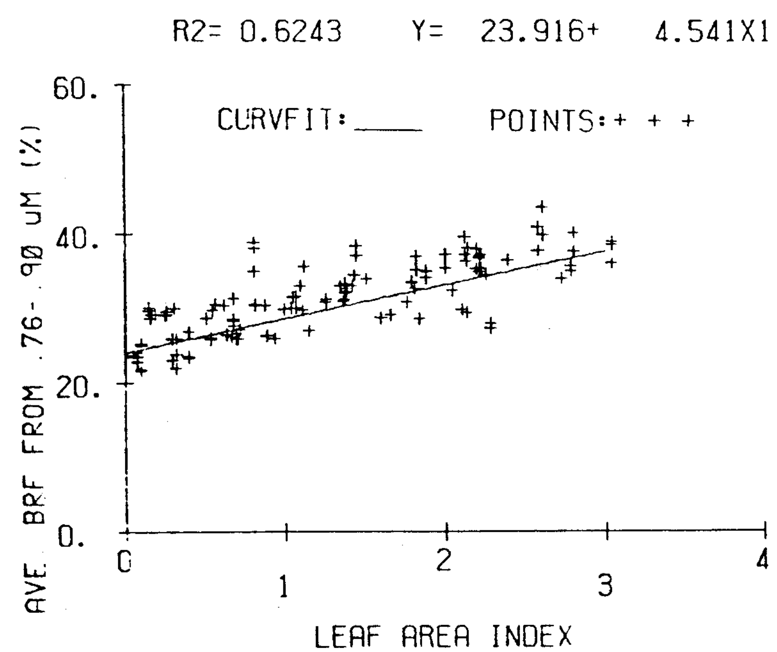

Figure B-5. Example of polynomial curve fitting using EXOSYDV software.

SEPARABILITY INFORMATION

I	J	D(I,J)	D(I)	D(J)	D(I)+D(J)	QUOT
1	2	6.762	4.310	4.465	8.775	0.771
1	3	13.082	4.216	4.779	8.996	1.454
1	4	20.646	3.773	6.411	10.184	2.027
1	5	28.462	4.242	6.120	10.362	2.747
1	6	34.623	3.297	5.227	8.524	4.062
1	7	41.177	2.924	3.097	6.021	6.839
2	3	6.423	4.472	4.860	9.332	0.688
2	4	14.067	4.348	6.645	10.993	1.280
2	5	21.754	4.283	6.358	10.641	2.044
2	6	28.154	4.011	5.569	9.580	2.939
2	7	34.868	3.777	3.282	7.059	4.940
3	4	7.864	5.229	6.714	11.943	0.658
3	5	15.560	5.273	6.689	11.962	1.301
3	6	21.983	5.011	6.112	11.123	1.976
3	7	28.759	4.725	3.292	8.017	3.587
4	5	8.350	5.775	7.484	13.259	0.630
4	6	14.154	6.352	6.490	12.842	1.102
4	7	20.996	6.241	3.800	10.041	2.091
5	6	8.311	6.720	5.912	12.631	0.658
5	7	15.343	6.124	3.470	9.593	1.599
6	7	7.147	6.070	4.695	10.765	0.664

AVERAGE QUOTIENT 2.098

RESULTS OF CLUSTER GROUPING

THRESHOLD = 0.750

GROUP	CLUSTERS	NO. PTS.
1		
	1	46
2		
	2	68
	3	73
3		
	4	127
	5	114
4		
	6	111
	7	99

Figure B-6. Example of cluster separability and grouping information available from EXOSYSDV.

FIELD HOMOGENEITY

FIELD/ PLOT	NO. PTS	PTS IN CLUSTER 1	2	3	4	5	6	7
1	7	0	0	0	3	4	0	0
2	11	6	4	1	0	0	0	0
3	8	0	1	1	3	2	1	0
4	7	0	1	1	3	2	0	0
5	9	1	4	1	3	0	0	0
6	7	2	2	1	2	0	0	0
7	9	1	4	0	4	0	0	0
8	8	1	0	3	3	1	0	0
9	11	0	1	5	3	2	0	0
10	8	0	2	2	2	2	0	0
11	9	0	1	3	2	3	0	0
12	8	1	3	2	2	0	0	0
13	11	0	1	1	7	1	1	0
14	9	1	0	5	2	1	0	0
15	9	0	1	1	4	0	3	0
16	10	2	1	4	2	1	0	0
17	12	0	1	1	8	2	0	0
18	12	1	4	4	3	0	0	0
19	10	0	2	1	0	3	4	0
20	8	0	1	1	0	2	3	1
21	10	0	1	0	0	4	3	2
22	11	0	1	0	1	2	4	3
23	9	0	2	0	0	5	1	1
24	9	0	1	0	1	3	1	3
25	11	0	1	0	0	5	2	3
26	12	0	1	0	1	4	1	5
27	10	0	2	0	1	2	2	3
28	8	0	1	0	0	2	3	2
29	20	0	1	0	1	6	5	7
30	21	0	1	0	0	7	6	7
31	18	0	2	0	0	4	3	9
32	17	0	1	0	1	2	8	5
33	10	0	1	0	0	5	2	2
34	12	0	1	0	2	2	6	1
35	7	0	0	0	0	2	4	1
36	5	0	0	0	1	4	0	0
37	10	7	1	2	0	0	0	0
38	7	1	0	2	3	1	0	0
39	10	2	4	2	2	0	0	0
40	9	1	0	1	3	1	3	0
41	7	1	2	2	2	0	0	0
42	8	1	4	1	2	0	0	0
43	7	2	0	0	2	0	3	0
44	7	1	0	2	4	0	0	0
45	7	1	0	2	2	0	2	0
46	8	1	0	2	2	0	3	0
47	9	2	0	2	4	1	0	0
48	8	1	0	2	5	0	0	0
49	6	1	0	0	1	1	3	0
50	6	1	0	0	2	3	0	0
51	11	2	1	3	1	4	0	0
52	8	1	0	2	4	0	1	0
53	6	1	0	2	3	0	0	0
54	9	2	0	1	5	1	0	0
55	7	1	0	0	2	1	2	1
56	6	0	1	0	1	1	2	1
57	7	0	1	0	1	1	0	4
58	8	0	0	2	0	1	1	4
59	8	0	0	1	2	0	1	4
60	7	0	1	0	1	1	2	2
61	8	0	0	1	0	0	4	3
62	9	0	0	2	0	1	1	5
63	8	0	1	0	2	0	2	3
64	6	0	0	1	0	0	2	3
65	8	0	1	0	2	1	4	0
66	8	0	0	0	2	1	3	2
67	7	0	0	0	2	1	3	1
68	8	0	0	0	0	2	1	5
69	10	0	0	0	0	2	3	5
70	7	0	0	0	0	4	2	1

Figure B-7. Example of field or plot homogeneity output indicating number of data points included in each cluster class.

EXOSYS(VER 2.2)
USER -- BIEHL

LABORATORY FOR APPLICATIONS OF REMOTE SENSING
PURDUE UNIVERSITY

NOV 14,1978
11 32 36 PM

CLASS STATISTICS

CLASS NAME	SPECTRAL BAND	BAND MEAN STATISTICS: MEAN	RANGE MINIMUM	RANGE MAXIMUM	VARIANCE	STANDARD DEVIATION	PERCENT DEVIATION	NO. RUNS	POINT STATISTICS: STANDARD DEVIATION	PERCENT DEVIATION	PTS IN BAND
CLU 1/ 7	0.450- 0.520	9.76	7.76	13.49	1.17	1.08	11.06	46	1.45	14.86	368
	0.520- 0.600	13.17	11.59	14.89	0.69	0.83	6.29	46	1.42	10.77	414
	0.630- 0.690	16.75	14.89	19.27	1.04	1.02	6.09	46	1.26	7.53	322
	0.760- 0.900	25.29	21.72	27.20	1.40	1.18	4.68	46	1.85	7.33	690
	1.550- 1.750	40.42	37.50	44.48	2.01	1.42	3.51	46	1.61	3.99	966
	2.080- 2.350	35.57	32.63	39.06	2.10	1.45	4.08	46	2.16	6.08	1288
CLU 2/ 7	0.450- 0.520	8.32	6.61	10.85	0.64	0.80	9.59	68	1.26	15.15	544
	0.520- 0.600	11.75	9.78	14.11	0.79	0.89	7.58	68	1.48	12.58	612
	0.630- 0.690	15.44	13.33	18.40	1.74	1.32	8.55	68	1.51	9.81	476
	0.760- 0.900	24.88	19.54	28.43	7.35	2.71	10.90	68	3.07	12.34	1020
	1.550- 1.750	36.87	33.32	39.34	1.16	1.08	2.92	68	1.32	3.59	1428
	2.080- 2.350	30.36	27.15	34.09	2.99	1.73	5.69	68	2.32	7.63	1904
CLU 3/ 7	0.450- 0.520	7.38	5.76	9.00	0.57	0.76	10.25	73	1.27	17.26	584
	0.520- 0.600	10.95	8.60	13.76	1.04	1.02	9.31	73	1.57	14.36	657
	0.630- 0.690	14.53	11.41	19.04	3.91	1.98	13.60	73	2.11	14.50	511
	0.760- 0.900	25.89	16.79	30.33	6.72	2.59	10.01	73	2.98	11.52	1095
	1.550- 1.750	33.47	30.28	35.77	2.08	1.44	4.31	73	1.71	5.10	1533
	2.080- 2.350	25.23	22.38	28.64	2.01	1.42	5.62	73	2.11	8.38	2044
CLU 4/ 7	0.450- 0.520	6.00	4.46	8.18	0.61	0.78	12.98	127	1.16	19.30	1016
	0.520- 0.600	9.09	7.26	11.90	0.84	0.92	10.09	127	1.31	14.38	1143
	0.630- 0.690	11.15	7.71	17.30	3.50	1.87	16.78	127	1.94	17.43	889
	0.760- 0.900	27.52	21.78	33.85	7.63	2.76	10.04	127	3.12	11.33	1905
	1.550- 1.750	29.34	26.22	33.03	2.09	1.44	4.92	127	1.87	6.37	2667
	2.080- 2.350	20.19	16.49	24.09	3.47	1.86	9.23	127	2.33	11.53	3556
CLU 5/ 7	0.450- 0.520	4.71	3.50	6.78	0.36	0.60	12.76	114	0.99	21.12	912
	0.520- 0.600	7.52	5.83	9.96	0.54	0.74	9.80	114	1.16	15.37	1026
	0.630- 0.690	9.69	5.37	13.46	3.22	1.79	18.52	114	1.87	19.33	798
	0.760- 0.900	25.21	18.51	31.92	13.50	3.67	14.57	114	3.96	15.70	1710
	1.550- 1.750	23.98	18.86	27.25	3.86	1.96	8.19	114	2.26	9.41	2394
	2.080- 2.350	14.77	10.77	18.14	3.23	1.80	12.16	114	2.20	14.87	3192
CLU 6/ 7	0.450- 0.520	3.75	2.64	6.76	0.47	0.69	18.31	111	0.94	25.16	888
	0.520- 0.600	6.06	4.71	8.31	0.70	0.84	13.83	111	1.03	17.06	999
	0.630- 0.690	6.19	4.41	10.84	1.36	1.17	18.86	111	1.19	19.28	777
	0.760- 0.900	30.90	22.93	36.56	6.92	2.63	8.51	111	3.01	9.74	1665
	1.550- 1.750	20.87	15.74	26.64	5.07	2.25	10.79	111	2.66	12.74	2331
	2.080- 2.350	11.34	7.14	15.62	3.38	1.84	16.20	111	2.10	18.55	3108
CLU 7/ 7	0.450- 0.520	2.89	2.02	4.87	0.32	0.57	19.64	99	0.79	27.42	790
	0.520- 0.600	4.74	3.73	6.06	0.35	0.59	12.50	99	0.78	16.54	891
	0.630- 0.690	4.00	2.65	5.30	0.34	0.58	14.51	99	0.63	15.80	693
	0.760- 0.900	34.94	27.09	43.65	13.80	3.71	10.63	99	4.00	11.46	1485
	1.550- 1.750	17.20	13.02	21.84	4.28	2.07	12.03	99	2.59	15.06	2079
	2.080- 2.350	7.60	5.06	10.69	1.90	1.38	18.14	99	1.64	21.63	2766

Figure B-8. Example of the statistics printed for each cluster class using the new statistics capabilities in EXOSYSDV.

C. Multicrop Field Research

Although the LACIE Field Measurements project (Bauer et al., 1978)[a] acquired a large quantity of spectral and agronomic data and analyses of it are providing quantitative information about the spectral characteristics of crops, the data are limited to crops grown in the Great Plains region of the United States. As we look ahead to the development of a global food and fiber information system utilizing remote sensing techniques, it is important to begin to conduct the field research required to more fully understand the spectral characteristics of crops other than wheat such as corn, soybeans, rice, cotton, and rangeland.

As part of the LACIE Transition and Multicrop program initiated in 1978, field research for corn and soybeans was initiated. The overall objectives of the multicrop supporting field research are:

- To increase the understanding of the basic radiation patterns of agricultural crops and their soil backgrounds under normal and stressed conditions.
- To assess the capability of current and planned satellite sensor systems to capture available useful spectral information.
- To determine the potential incremental improvement in performance of improved future systems.

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*This section describing the results of work conducted as part of Task 2B, Application and Evaluation of Landsat Training, Classification, and Area Estimation Procedures for Crop Inventory, was prepared by C.S.T. Daughtry and B.F. Robinson. The Multicrop Field Research project was led by Dr. Marvin Bauer. The field measurements of corn and soybeans were directed by Dr. Craig Daughtry. Barrett Robinson and Larry Biehl were responsible for the spectral measurements. Jeff Kollenkark, Greg Walburg, David Longer, Michael Stabenfeldt, and Vic Fletcher assisted in the data collection. The field research instrumentation task was directed by Barrett Robinson. Professors David DeWitt and Leroy Silva made major contributions to development of the instrument system specifications.

[a] Bauer, M.E., M.C. McEwen, W.A. Malila, and J.C. Harlan. 1978. Design, Implementation, and Results of LACIE Field Research. Proceedings, LACIE Symposium. October 23-26, 1978. NASA, Johnson Space Center, Houston, Texas.

The multicrop field research at Purdue/LARS during this contract year consisted of two components. The first was the acquisition of data describing the spectral properties of corn and soybeans under normal and stressed conditions. These experiments, conducted at the Purdue Agronomy Farm, are described in Section 1.

The second component of the project, described in Section 2, was development of specifications for a new approach to spectral measurements for field research. The primary sensors used for LACIE Field Measurements were spectrometers capable of producing high-resolution spectra. In the future a new approach to the collection of field measurements data will be needed since it will not be feasible simply to multiply the current approach by the increased number of crops and regions which should be included in future experiments. Multiband radiometer systems can economically provide the necessary spectral measurements. With these instruments it will be possible to acquire measurements at more sites than is possible with the currently available high-spectral resolution spectrometer systems. And, it is more observations of crops and soils under a wide variety of conditions (not detailed spectral measurements of a limited number of locations and crop conditions) that is needed to increase our understanding of the spectral characteristics of agricultural scenes. There will be a continuing need for the high-resolution spectrometer systems to be utilized in field research, but less complex systems are also required which can be used to make large numbers of measurements at many sites economically and accurately.

1. MEASUREMENTS OF SPECTRAL CHARACTERISTICS OF CORN AND SOYBEANS

The potential of remote sensing to provide information on the condition and yields of crops has not been adequately explored and developed, especially for corn and soybeans. This task represents the initial phase of a multiyear research effort to evaluate and understand information about corn and soybeans crops contained in various types of remotely sensed data. The results of these carefully controlled field experiments can provide the foundation on which larger experiments involving Landsat data should be built.

1.1 Objectives

The overall objectives of this field research task which include data acquisition and analysis are:

1. To determine the reflectance characteristics of corn and soybeans as a function of maturity stage and amount of vegetation present.

2. To examine the effects of moisture and nutrient stresses on the reflectance and radiant temperatures of corn and soybeans.

3. To determine the effect of important cultural/management practices on the reflectance of soybeans.

4. To develop and assess various methods of incorporating spectral, meteorological, and ancillary data into models of crop condition assessment and yield prediction.

Activities this year towards fulfillment of these objectives include collection of spectral, agronomic, and meterological data at the Purdue University Agronomy Farm for five experiments with two different spectrometer systems.

1.2 Description of Experiments and Measurements

Several specific experiments have been established at the Purdue Agronomy Farm to address the above objectives. The experiments, described in the implementation plan, were: (1) corn moisture stress,

(2) nitrogen fertilization of corn, (3 and 4) phosphorous and potassium fertilization of corn and soybeans, and (5) cultural practices of soybeans. The experiments provide both normal and stressed conditions of corn and soybeans. Spectral and agronomic data were collected at approximately weekly intervals throughout the growing season.

Spectral measurements were made with the Exotech 20C high resolution spectrometer system and the Exotech 100 Landsat-band radiometer (Figure C-1). The Exotech 20C field system collected data over the 0.4 to 2.4 μm range. The Exotech 100 field system which is a prototype of a more advanced multiband radiometer systems, (see Section 2), collected data in the four Landsat MSS bands .5-.6, .6-.7, .7-.8, .8-1.1 μm. The spectral data were calibrated using 1.2 meter square painted barium sulfate standards.

Augmenting the reflective measurements were radiant temperature measurements collected by Barnes PRT-5 instruments and oblique ground level and overhead photographs of the plots. The meteorological data included air temperature, barometric pressure, relative humidity, wind speed, and wind direction. A record of the irradiance was collected on pyranometer strip charts. Additional environmental data were acquired hourly by a computerized agricultural weather station located on the Agronomy Farm.

Detailed agronomic measurements of the crop canopies included leaf area index, fresh biomass, dry biomass of leaves, stems, and ears (pods for soybeans), heights, maturity stage, percent of soil cover, and soil moisture. Leaf samples were collected and dried for nutrient analysis. Grain yields were measured at harvest.

The approach to each of the objectives is briefly summarized below. The first of the overall objectives of this task was accomplished in the course of conducting specific experiments for Objectives 2 and 3. Spectra of normal (unstressed) corn and soybeans will be assembled and plotted to represent their reflectance as a function of maturity stage, biomass, leaf area index, height, and percent soil cover.

Fi

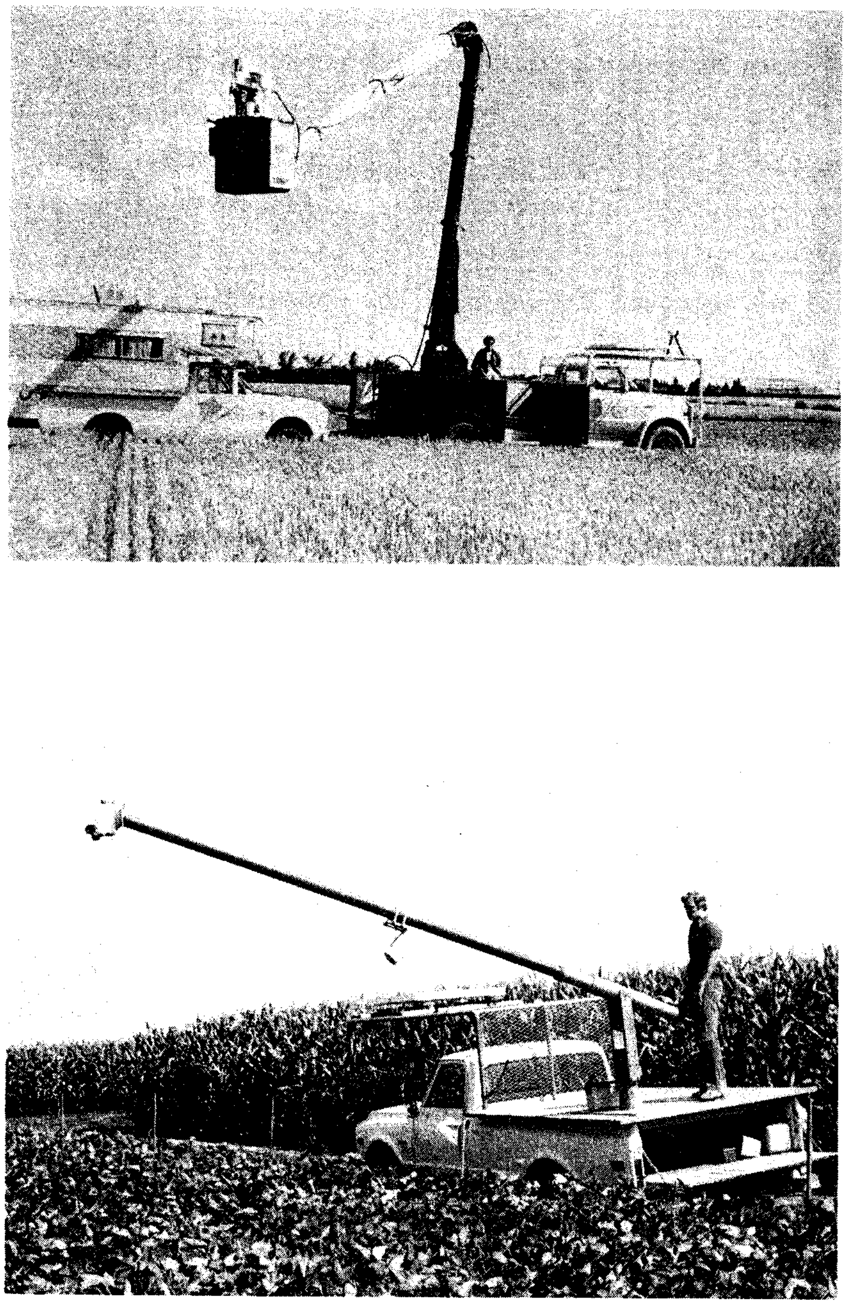


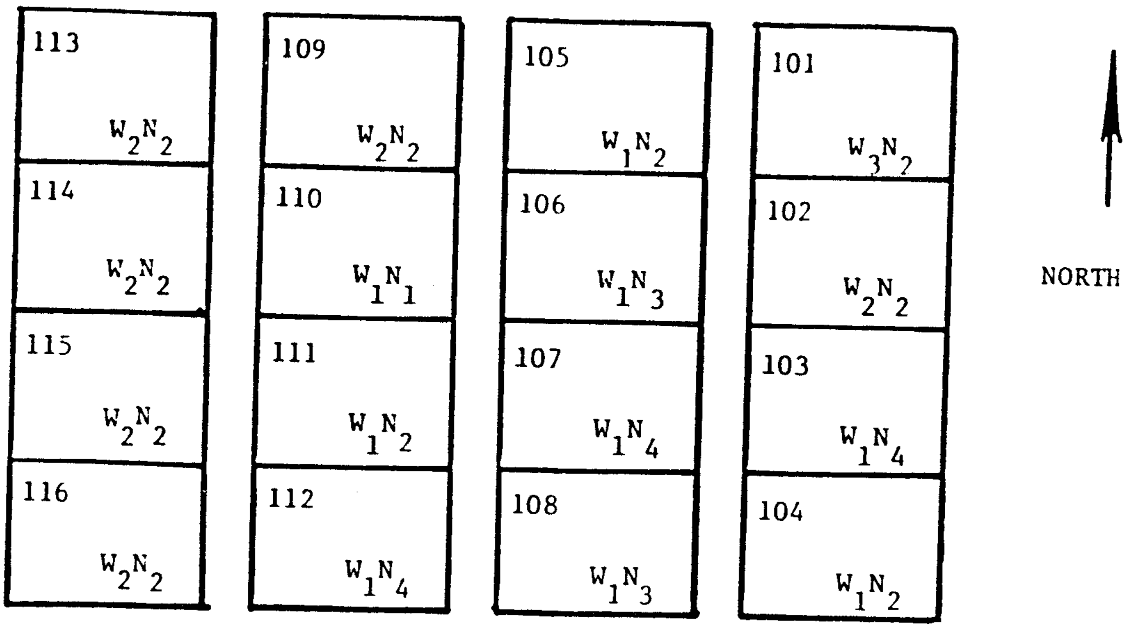
Figure C-1. Spectroradiometer (top) and multiband radiometer (bottom) systems used for measuring spectral characteristics of corn and soybeans.

To accomplish the second objective four experiments were conducted; one on corn moisture stress and three on nutrient stresses. Spectral and agronomic data were acquired at major maturity stages. The moisture stress experiment (Figure C-1) was established on the Managed Soil Moisture System (MSMS). The MSMS facility is a series of plastic-lined plots equipped with pipes and pumps so that water and/or nutrient supply can be controlled and either type of stress can be imposed on the crop (Reetz, <u>et al.</u> 1978). Spectral reflectance, radiant temperatures, and agronomic characterizations of the stressed and nonstressed canopies were acquired once per day at seven to 10 day intervals. On selected days during the season, reflectance, radiant temperature, and leaf water potential were measured four to eight times to monitor the diurnal changes in these parameters due to stress.

Nutrient deficiencies of corn and soybeans were studied on a Raub silt loam soil on which crop responses to residual and applied nutrients have been monitored for more than 20 years (Barber, 1970). Corn growth, development, grain yields and spectral reflectance were measured at four levels of applied nitrogen fertilizer (Figure C-2). Spectral reflectance of corn and soybean canopies growing at different levels of soil phosphorous and potassium also were examined at their major maturity stages from seedling to harvest (Figure C-3).

The third experiment examined the effects of different plant types, planting densities (within row spacings), and row spacing on the reflectance of soybeans (Figure C-4). Reflectance data acquired with the Exotech 100 system along with measurements of canopy variables (biomass, height, ground cover, etc.) will be used not only for characterizing the reflectance of soybeans, but also for examining the physical basis for increased soybean production at narrow row spacings.

The fourth objective involved the assimilation of the data collected in these experiments into information which can be used in crop models to evaluate crop growth and to predict yields during the growing season. This objective represents one of the long range goals of this task and during the contract year consisted primarily of the preliminary conceptual



<u>Water Stress</u>

W_1 = Well watered

W_2 = Slight stress

W_3 = Moderate Stress

<u>Nitrogen Stress</u>

N_1 = 168 Kg/ha

N_2 = 336 Kg/ha

N_3 = 504 Kg/ha

N_4 = 672 Kg/ha

Figure C-2. Design and treatment descriptions of moisture and nitrogen stress experiments on Managed Soil Moisture System plots.

Treatment Code		Nitrogen Applications
A	=	Check plot, no nitrogen
B	=	67 Kg/ha N as anhydrous ammonia
C	=	134 " " " " "
D	=	202 " " " " "
E	=	67 Kg/ha of N as urea
F	=	134 " " " " "
G	=	202 " " " "
H	=	269 Kg/ha of N as urea in alternate years
I	=	403 " " " " " " " "
J	=	134 " " " " " " " "
K	=	67 Kg/ha of N as urea in fall
L	=	134 Kg/ha " " " " " "

North

	Plot No.	Treatment Code	
	701	B	Block 1
*	702	E	Block 1
*	703	F	Block 1
	704	H	Block 1
	705	L	Block 1
	706	C	Block 1
*	707	D	Block 1
*	708	A	Block 1
*	709	J	Block 1
	710	G	Block 1
	711	I	Block 1
	712	K	Block 1
	713	L	Block 2
	714	K	Block 2
	715	B	Block 2
	716	I	Block 2
	717	D	Block 2
	718	J	Block 2
*	719	G	Block 2
*	720	A	Block 2
*	721	E	Block 2
*	722	F	Block 2
	723	H	Block 2
	724	C	Block 2
	725	H	Block 3
	726	I	Block 3
	727	F	Block 3
	728	B	Block 3
	729	J	Block 3
	730	C	Block 3
*	731	A	Block 3
*	732	E	Block 3
*	733	L	Block 3
*	734	G	Block 3
	735	D	Block 3
	736	K	Block 3

Figure C-3. Design and treatment descriptions of corn nitrogen fertilization experiment. Spectral measurements were made of plots marked with an asterik (*).

North

Plot No.	Trt. Code	
433	J	
434	T	
435	Q	
436	L	
437	D	
438	V	
439	R	
440	G	
441	S	
442	F	
443	B	
444	O	
445	I	
446	U	
447	E	
448	K	
449	N	
450	H	
451	M	
452	P	
453	A	
454	C	

Wheat

Plot No.	Trt. Code	
389	P	
390	N	
391	H	
392	V	
393	A	
394	C	
395	U	
396	M	
397	Q	
398	E	
399	R	
400	L	
401	J	*
402	S	*
403	T	
404	G	
405	I	
406	D	
407	B	
408	O	
409	K	
410	F	

Corn(2)

Plot No.	Trt. Code	
345	D	
346	R	*
347	S	*
348	G	*
349	T	*
350	B	*
351	I	
352	L	
353	A	
354	C	*
355	K	*
356	H	*
357	N	
358	P	
359	M	
360	O	
361	J	
362	F	
363	V	
364	E	
365	U	
366	Q	

Soybeans

Plot No.	Trt. Code	
301	F	
302	E	
303	I	
304	K	*
305	O	*
306	J	
307	N	
308	H	*
309	P	*
310	G	*
311	D	
312	U	
313	A	
314	Q	
315	V	
316	L	
317	S	
318	C	*
319	T	*
320	R	*
321	M	
322	B	*

Corn(1)

455	T	*
456	G	*
457	B	*
458	R	*
459	O	*
460	C	*
461	M	
462	D	
463	N	
464	I	
465	K	
466	S	*
467	Q	*
468	P	*
469	H	*
470	J	
471	E	
472	U	
473	A	
474	F	
475	V	
476	L	

Soybeans

411	M	
412	I	
413	N	
414	Q	
415	L	
416	J	
417	A	
418	U	
419	G	*
420	E	
421	P	*
422	V	
423	B	*
424	F	*
425	S	*
426	T	*
427	K	
428	D	
429	H	*
430	R	*
431	O	*
432	C	*

Corn (1)

367	S	
368	E	
369	L	
370	U	
371	P	
372	H	
373	V	
374	Q	
375	F	
376	M	
377	R	
378	T	
379	K	
380	D	
381	C	
382	A	
383	I	
384	O	
385	G	
386	J	
387	N	
388	B	

Wheat

323	O	
324	A	
325	K	
326	I	
327	F	
328	E	
329	R	
330	T	
331	C	
332	B	
333	H	
334	G	
335	U	
336	J	
337	M	
338	N	
339	V	
340	L	
341	P	*
342	Q	
343	S	*
344	D	

Corn(2)

Figure C-4. Design and treatment descriptions of phosphorous and potassium fertilization experiments. Spectral measurements were made on plots marked with an asterik (*).

Figure C-4. continued.

Treatment Code	Broadcast P_2O_5	Broadcast K_2O	Band P_2O_5	Band K_2O
	Pounds/Acre*			
A	100	100	40	40
B	100	200	0	0
C	100	200	40	0
D	100	200	100	0
E	100	200	200	0
F	100	500	40	0
G	100	500	100	0
H	100	500	200	0
I	200	200	0	0
J	200	200	40	0
K	200	200	100	0
L	200	500	0	0
M	200	500	40	0
N	200	500	100	0
O	500	100	40	0
P	500	100	40	100
Q	500	200	0	0
R	500	200	40	0
S	500	200	40	100
T	500	500	0	0
U	500	500	40	0
V	500	500	100	0

*Treatments are the entire amounts of fertilizer applied during four year rotation (corn-soybeans-wheat-corn).

NORTH

Block 1 Plot No.	Block 1 Treatment R V P	Block 2 Plot No.	Block 2 Treatment R V P	Block 3 Plot No.	Block 3 Treatment R V P	Block 4 Plot No.	Block 4 Treatment R V P
501	1 3 2	528	1 3 2	555	1 2 2	582	2 1 2
502	1 2 2	529	2 1 2	556	3 1 2	583	2 2 2
503	3 1 1	530	2 1 3	557	1 2 1	584	2 2 3
504	2 1 2	531	3 1 3	558	1 1 1	585	3 2 2
505	3 1 2	532	3 2 1	559	3 3 3	586	1 3 2
506	2 1 1	533	3 3 3	560	1 3 1	587	2 3 1
507	1 2 1	534	1 1 3	561	1 3 2	588	1 2 1
508	2 2 1	535	1 2 3	562	3 3 2	589	1 2 3
509	3 3 2	536	3 1 1	563	2 3 3	590	1 3 1
510	3 2 3	537	1 2 2	564	3 1 1	591	2 1 3
511	3 1 3	538	1 2 1	565	1 2 3	592	3 2 1
512	2 3 2	539	1 1 1	566	2 3 2	593	3 1 3
513	1 1 1	540	3 2 3	567	2 1 1	594	3 1 2
514	3 2 1	541	1 3 1	568	3 2 2	595	1 2 2
515	1 1 3	542	2 2 2	569	3 2 1	596	3 3 2
516	1 2 3	543	3 2 2	570	2 3 1	597	1 1 3
517	3 2 2	544	2 2 1	571	1 1 3	598	1 1 1
518	2 1 3	545	3 3 1	582	2 2 2	599	3 3 2
519	1 3 1	546	3 3 2	573	1 1 2	600	3 1 1
520	3 3 3	547	3 1 2	574	2 1 3	601	2 3 2
521	2 2 2	548	2 3 1	575	3 2 3	602	3 2 3
522	1 3 3	549	2 2 3	576	2 1 2	603	3 3 3
523	2 2 3	550	1 1 2	577	2 2 1	604	2 1 1
524	1 1 2	551	2 3 2	578	3 3 1	605	1 1 2
525	2 3 1	552	2 1 1	579	3 1 3	606	2 2 1
526	3 3 1	553	2 3 3	580	1 3 3	607	2 3 3
527	2 3 3	554	1 3 3	581	2 2 3	608	1 3 3

Row Spacing

R1 = 15 cm
R2 = 46 cm
R3 = 91 cm

Variety

V1 = Amsoy 71
V2 = Wells
V3 = Elf

Population

Amsoy 71 & Wells	Elf
P1 = 111 K plants/ha	P1 = 185 K plants/ha
P2 = 185 K	P2 = 259 K
P3 = 259 K	P3 = 334 K

Figure C-5. Design and treatment descriptions of soybean cultural practices experiment.

development of crop yield models which will incorporate spectral, meteorological, and ancillary data.

When the data acquired in this task are processed, various types of plots of the reflectance, radiant temperature, agronomic, and meteorological data will be made to verify data quality and to assess qualitatively the information contained in the data. Spectral data will be represented in several ways for analysis: band means for Landsat and the proposed thematic mapper bands; and transformations of the reflectance values such as IR/red ratio and greenness-brightness. Canopy radiant temperature data will be represented as absolute temperatures, as relative temperature differences (canopy temperature minus air temperature), and as accumulated relative differences in temperature during critical growth phases. (Idso, et al., 1977; Jackson et al., 1977). Regression and correlation analyses will be used to relate biological and physical parameters of the canopies, such as leaf area index, biomass, height, leaf water potential, and maturity stage to measures of spectral response and radiant temperatures. Analyses of variance and covariance will be used to determine the threshold of detection and the separability of various levels of stress from each other.

1.3 Data Collection and Processing

Spectral measurements, along with agronomic and meteorological data, have been acquired on every day that weather conditions permitted. A summary of the data collection (number of observations per experiment) is shown in Tables C-1 and C-2. Crop maturity stages from seedling to senescence for 1978 are represented in these data.

The cool wet weather of the spring of 1978 delayed soil preparation and corn planting at the Agronomy Farm and necessitated some modifications in the experiments planned. The Russell soil on which the corn irrigation experiment was to be planted remained too wet for plowing until earlyJune. On June 9 (a full month after the optimum planting data for corn) the first corn of this experiment was planted. This

date was too late to include a series of later planting dates as indicated in the implementation plan. Instead an experiment on the effects of soil surface moisture was conducted.
Reflectance and radiant temperature data were collected over eight plots of corn at two different maturity stages with contrasting amounts of soil cover.

More frequent rains then normal during the summer also made establishment and maintenance of different levels of water stress nearly impossible. Short-term differences in soil moisture were established on several occasions in late July and August and radiant temperature and water potential were measured. However, much valuable experience on growing corn in the sand of the MSMS plots was gained, which should contribute more efficient operation of this facility in 1979.

The data acquired during the summer and fall are currently being processed and prepared for analysis. Analysis of the data is planned to start in early 1979.

1.4 References

Barber, S.A. 1970. Effect of rate and placement of phosphorous and potassium on a rotation, 18 year period. Research Progress Report 365, Purdue University Agric. Expt. Station, West Lafayette, Indiana.

Idso, S.B. R.D. Jackson, and R.J. Reginato. 1977. Remote sensing of crop yields. Science 196:19-25.

Jackson, R.D. R.J. Reginato, and S.B. Idso 1977. Wheat canopy temperature: A practical tool for evaluating water requirements. Water Resources Research 13:651-656.

Reetz, H.F. Hodges, and R.F. Dale. 1978. Managed soil moisture system for studying plant water relations under field conditions. Crop Science 18: (in press).

Table C-1. Summary of 1978 data acquisition on corn and soybean experiments (number of observations) by the Exotech 100 data acquisition system.

Measurement Dates	Corn			Soybean	
	Moisture Stress	Phosphorous -Potassium Fertilization	Nitrogen Fertilization	Phosphorous -Potassium Fertilization	Management Practices
June 18-24	96	-	-	-	54
June 25-July 1	-	92	48	66	-
July 2-8	84	70	48	84	332
July 9-15	48	46	26	64	162
July 16-22	-	-	-	-	171
July 23-29	-	-	-	-	162
July 30-Aug. 5	-	-	-	22	218
August 6-12	-	46	26	42	54
August 13-19	-	46	20	-	108
August 20-26	16	46	-	40	162
August 27-Sept. 2	-	-	-	-	162
September 3-9	-	46	26	42	-
September 10-17	-	-	-	-	-
September 17-23	-	-	-	-	108
October 15-21	-	-	-	-	136
Seasonal Totals	244	392	246	360	1829

Grand Total 3071

Table C-2. Summary of data 1978 acquisition on corn and soybean experiments by the Exotech 20C data acquisition system.

Dates	Corn				Soybean	
	Moisture Stress	Phosphorous -Potassium Fertilization	Nitrogen Fertilization	Canopy -Soil	Phosphorous -Potassium Fertilization	Management Practices
June 11-17	28	14	-	-	-	-
June 18-24	-	-	-	-	-	-
June 25-July 1	6	-	20	-	10	-
July 2-8	6	48	33	-	56	-
July 9-15	97	16	15	-	6	-
July 16-22	8	16	-	16	29	-
July 23-29	-	18	17	-	-	-
July 30-August 5	8	29	17	-	25	-
August 6-12	41	-	-	-	-	-
August 13-19	-	-	16	-	5	-
August 20-26	8	32	17	16	28	-
August 27-Sept. 2	4	-	17	-	-	-
September 3-9	-	32	-	-	28	-
September 10-16	-	-	17	-	10	-
September 16-23	-	-	17	-	15	33
Seasonal Totals	206	205	186	32	212	33
Grand Total 874						

2. SPECIFICATION OF A STANDARDIZED MULTISPECTRAL DATA ACQUISITION SYSTEM FOR FIELD RESEARCH.

2.1 Introduction

To develop the full potential of multispectral data acquired from satellites, increased knowledge and understanding of the spectral characteristics of specific earth features is required. Knowledge of the relationships between the spectral characteristics and important parameters of earth surface features can best be obtained by carefully controlled studies over areas, fields, or plots where complete data describing the condition of targets is attainable and where frequent, timely spectral measurements can be obtained. The currently available instrumentation systems are either inadequate or too costly to obtain these data. Additionally, there is a critical need for standardized acquisition and calibration procedures to ensure the validity and comparability of data.

The overall, long-term objective of this project is to develop a multispectral data acquisition system which will improve and advance the capability for remote sensing field research. The specific objectives are to:

1. Specify, develop and test the prototype of a radiometric instrument system.
2. Develop and document calibration, measurement and operation procedures.
3. Develop software for data handling capability.

The radiometric instrument will be a multiband radiometer with up to 8 bands between 0.4 and 2.4 μm. The data acquisition system will record data from the multiband radiometer, a radiation thermometer, and ancillary sources. The radiometer and data handling systems will be adaptable to helicopter, truck, or tripod platforms.

The general characteristics of the system are that it will be: (1) comparatively inexpensive to acquire, maintain, and operate;

(2) simple to operate and calibrate; (3) complete with data handling hardware and software; and (4) well-documented for use by researchers.

The specific results of the project will be: (1) a multiband radiometer; (2) a data acquisition and handling system; (3) a machine independent software package; and (4) a comprehensive system manual documenting the design and use of the above. The most significant result will be the establishment of the capability for researchers to acquire the data to effectively investigate relationships between the physical-biological and the multispectral characteristics of crops, soils, forests, water, and geological features.

The instrument system will be a prototype of an economical, standardized system which can be utilized by many researchers to obtain large numbers of accurate, calibrated spectral measurements. As such it is a key element in improving and advancing the capability for field research in remote sensing.

2.2 General Characteristics of the Instrument System

The complete instrument system will provide the researcher with the means to acquire multispectral data with near optimum coverage of the spectrum from a variety of platforms ranging from hand-held operation to operation from a helicopter or small aircraft. The data playback feature will enable the researcher to check completely the performance of the system and measurement procedures in the field. The data playback feature will also serve as a means to enter the gathered data directly into a digital computer using the acquisition module as the interface.

Specifications for the instrument system will be established with adherence to four principles to enhance the eventual commercial availability of the system and adoption of the system by the remote sensing community.

(1) The specifications will emphasize a modular design. The design will allow for system expansion or alteration through addition or substitution of modular building blocks. Design requirements will include that the instruments be functionally flexible and easy to understand, trouble-shoot, and repair.

(2) The final system will be assembled from commercially available (from the chosen vendors) modules and will require essentially no electronic or mechanical construction.

(3) Only hardware employing accepted signal processing techniques will be specified in the system.

(4) The final system must be easily operated by persons with diverse backgrounds and limited electronics training and easily repaired by persons with minimal electronics training.

The modular design approach will make possible the purchase of the particular system best matched to individual research goals and resources. The lowest cost (and least flexible) system would require only the radiometer module plus a multiple position switch and digital voltmeter. With this simple system, radiometric data would be acquired by sampling each output channel of the radiometer and manually recording the voltage.

A second, more complete system would require the radiometer module, plus a data handling module. The data handling module would convert the analog signals from the radiometer to digital numbers and print them on paper tape for later analysis.

A third system would entail expansion of the data system to include a digital recording and playback capability. In this expanded system the paper tape data optionally printed by the data handling module would serve to verify (in the field) the accuracy of the data stored by the data storage medium.

The general specifications for each of the modules follow:

<u>Multiband Radiometer Module</u>

The purpose of the multiband radiometer module is to simultaneously produce analog voltages which are proportional to the scene radiance in each of the spectral bands. The general specifications of the radiometer module are:

- Rugged, lightweight, and portable
- Battery operated
- Relatively low cost
- Eight spectral bands from 0.4 to 12.5 micrometers (Tentative band selection is 1.45-0.52, 0.52-0.58, 0.63-0.69, 0.76-0.90, 1.10-1.30, 1.55-1.75, 2.08-2.35, 10.5-12.5. This selection includes the seven Thematic Mapper bands and an additional band in the near infrared.)
- Optical filters to define each spectral band
- Optical units to be exchangeable to obtain the spectral pass bands desired by the researcher
- Selectable field of view (by lens substitution)
- All radiometric data simultaneously available in parallel format.

Data Handling Module

The data handling module will convert the signals from the radiometer to digital format and store them with digital ancillary data (i.e., date, time, observation number) in a removeable solid state module having a data retention battery. The data handling module will print data, compute reflectance or radiance, and also serve as the interface to enter data to digital computers and peripherals. The general specifications of the data handling module are:

- Rugged, lightweight, and portable
- Battery operated
- Relatively low cost
- Parallel multichannel analog input port compatible with analog outputs of radiometer
- A simultaneous sample and hold circuit for each detector channel (or equivalent)
- Remote activation of the acquisition sequence enabling synchronous operation with boresighted cameras operated by intervalometers
- Provision to enter date, time and observation number

- Digital hard copy printer to tabulate data values of each radiometer channel, plus ancillary data
- Digital data output port for RS 232-C and "12-bit parallel" with request to send/clear to send lines
- Auxilliary analog input ports to accomodate signals from other sensors such as the Barnes PRT-5 thermal sensor
- Provision for reflectance factor or radiance computations.

Documentation and User Training

In order for researchers to acquire accurate and comparable measurements it will be important to fully document and describe use of the instrument system. An educational package including audio-tutorial materials is being planned. It would provide researchers with the theoretical and practical knowledge to gather, process, and analyze high quality spectral data. Major topics to be treated are:

(1) Measurement and calibration fundamentals and procedures, including important parameters of the measurement situation and procedures for data evaluation and comparison.

(2) Specifications for the radiometer and instrument system, system tests, and typical results.

(3) Methods of positioning the instrument, including suggested hardware and mounting techniques for operation on a helicopter, mobile tower, and tripod platforms.

(4) Data handling and data processing procedures including a machine independent computer program to organize and present the data.

(5) Case studies of typical experiments including experimental design, measurement and data handling procedures, and analysis techniques and results.

2.3 Objectives

The objective for this contract year was to coordinate development of the specifications and the preparation of a draft request for quotation (RFQ) for a portable, inexpensive field instrument system with multiple, selectable, spectral bands to measure, record, and organize large amounts of high quality spectral data.

2.4 Approach

This effort was the initial step required to acquire instrumentation needed for meaningful field research; i.e., development of an inexpensive standardized, versatile field instrument to provide calibrated intercomparable spectral data when used by researchers at different sites.

The general characteristics of the radiometer and data acquisition system were presented to and discussed with active remote sensing researchers at other institutions with regard to their experimental needs and data handling preferences and capabilities. Potential vendors were contacted for their reaction to the specifications. Vendors were encouraged to suggest alternate means to obtain a practical, effective, commercially available hardware system. Final specifications will be prepared in cooperation with personnel from NASA/JSC.

A formal request for quotation will be prepared for submission to qualified vendors. The goal will be to ensure that each subsystem will be available for purchase on a continuing basis from a reliable supplier. The document will be prepared in cooperation with personnel from NASA/JSC.

Initial Discussions

Initial discussions held with Earth Observation Division (EOD) and Earth Resources Program Office administrators at NASA/JSC in the Spring of 1978 indicated that the proposed system could play a major role in supporting future research in remote sensing. As a result of these discussions, the EOD directed LARS to undertake, in the summer and fall of 1978, the task of developing the specifications of the instrument to the point where a formal RFQ can be prepared.

Contacts with Researchers and Potential Users

On May 24, 1978, a meeting of NASA and USDA researchers was hosted by the USDA/Science and Education Administration facility at Weslaco, Texas. Discussions of the preliminary specifications were led by Purdue/LARS researchers and the need for the system was confirmed. During the contract year, the specifications were also discussed with other scientists from England, France, Germany, and the U.S. Their comments and suggestions were considered in the definition of the specifications. In each case, the need for the system was expressed by the researcher.

Following the contacts with researchers and vendors, a more detailed set of preliminary specifications and system configuration alternatives was prepared and presented to the participants of the Weslaco meeting and to researchers from ERIM and the University of Nebraska. On October 12, a meeting was held at Purdue/LARS to discuss these specifications.

Contacts with Potential Vendors

In June 1978 potential vendors were provided copies of an "Informal Request for Consideration" which listed potential specifications for the Data Logger and the Multiband Radiometer Modules. During the summer, Professors Silva and DeWitt made follow-up calls to interested vendors. Professor Silva visited eight vendors to discuss the data logger. Professor DeWitt visited two vendors with regard to the multiband radiometer. A third vendor interested in developing the multiband radiometer module has been in telephone contact.

Preparation of Specifications

Preparation of tentative detailed specifications was completed in August and the specifications for the Radiometer and Data Module were forwarded to interested manufacturers and potential users for their reactions and suggestions. The first draft of the specifications for the RFQ was completed in September 1978.

Significant developments in the specifications for the multiband radiometer are the probable inclusion of a thermal infrared channel, 10.5 to 12.5 μm, and the use of temperature compensated detectors. Significant developments in the specifications for the data logger are the capacity for direct reflectance computation and the use of removeable semi-conductor data storage (instead of magnetic tape). As well as providing more easily interpreted feedback in the field, these features will enable many researchers to efficiently process all their data to bidirectional in-band reflectance factor (or thermal band radiance) using only the data acquisition module.

Field Tests

An experimental truck-mounted boom was constructed and tested for measurement of Landsat band bidirectional reflectance factor and radiant temperature. An Exotech Model 100, a Barnes PRT-5 and a motor dirve camera were mounted on the boom (see Figure C-1). The system was used for measurements of corn and soybean canopies from altitudes of 6 and 4 meters, respectively. The routine use of this system provided experience which will lead to improved design for an easy to construct, inexpensive, pick-up truck operated system which is sufficiently versatile to serve a large number of researchers.

Helicopter operation of the Exotech Model 100 boresighted with a camera was accomplished with the funds of other agencies and projects. Calibration was accomplished on-site with a canvas reflectance panel. The instrument and data acquisition system performed correctly and it was demonstrated that an untrained crew could quickly learn to perform the calibration and data acquisition operations.

2.5 Plans for Next Contract Year

During the next year the following tasks and accomplishments leading to commercial availability and use of the instruments in 1980 are planned:

- A review panel will be established to review the development, procurement and testing of the system
- A prototype system will be acquired and tested by Purdue/LARS
- Based on tests of the prototype system, final specifications for production units will be prepared
- A system manual will be prepared
- An experimenters' manual will be prepared
- Software for storage and use of radiometric and ancillary data will be developed.

D. Determining the Climatic and Genetic Effects on the Relationships between Multispectral Reflectance and Physical-Chemical Properties of Soils*

1. INTRODUCTION

Although a large body of knowledge has been accumulated about the physical and chemical characteristics of soils as they are influenced by the soil forming factors of climate, parent material, relief, biological activity, and time, there is only limited knowledge of how these factors relate to the reflected radiation from surface soils. Earlier studies have shown that information about the spectral properties of soils may be useful in their identification and characterization (1,2,3,4).

If present satellite sensors and the improved sensor systems planned for future satellites are to be used most effectively in the preparation of land use capability maps and soil productivity ratings as these relate to crop production, it is crucial to define quantitatively the soil variables related to productivity which can be measured by or correlated with multispectral radiation from the surface soil. This research seeks to contribute significantly to the understanding of the multispectral reflectance of soils as it relates to climate, physical and chemical properties of soils, engineering aspects of soil use and potential agricultural productivity.

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*This section describing the results of Task 1C, Determining the Climatic and Genetic Effects of the Relationships between Multispectral Reflectance and Physical-Chemical Properties of Soils, was prepared by the task manager, Eric Stoner. Prof. Marion Baumgardner and Dr. Richard Weismiller are co-leaders of this task. Barrett Robinson and Larry Biehl were responsible for the spectral measurements. Lou Nash, Steve Jordan, Charles Baker, Lyn Kirschner, and staff of the Purdue Soil Characterisation Lab made the chemical and physical measurements. Prof. Virgil Anderson assisted with the experiment design.

1.1 Quantification of Soil Properties

Modern soil classification systems emphasize the importance of information about the quantitative compositions of soils. In order to differentiate among soil groups, it is necessary to rely on laboratory measurements of selected soil properties. Physical, chemical, and engineering determinations of most soil properties follow well established procedures of laboratory analyses. Certain of these soil properties are selected as diagnostic criteria in the soil classification process, based on their importance in understanding the genesis of the soil. By a procedure of empirical correlation, critical limits between sets of soils are established, designed to reflect the influence of the soil forming factors of climate, parent material, relief, biological activity, and time.

Quantitative measurements of soil spectral properties have become available as a diagnostic tool for the soil scientist with the advent of such instruments as the Exotech Model 20C spectroradiometer. However, the climatic and genetic effects on the relationships between measured spectral properties and specific chemical, physical, and biological properties of the soil are not well understood. Whereas soil color is used as diagnostic criterion in the U.S. Soil Taxonomy (5), the determination of soil color by comparison with a color chart continues to be a rather nonquantitative and subjective procedure. Spectral characterization of soil "color" by means of quantitative spectroradiometric measurements may add to the precision with which soils can be differentiated. With this increased precision of soil spectral characterization, the relationships with the more important diagnostic soil characteristics or qualities that are not so easily and accurately observed may be better understood.

2. STUDY OBJECTIVES

The general objective is to define quantitatively the relationships between soil reflectance and physicochemical properties of soils of significance to agriculture and engineering. Selection of soil samples with a wide range of important soil characteristics by statistical stratification of continental United States climatic zones permits the evaluation of climatic and genetic effects on the relationships between multispectral reflectance and these soil properties. A further objective is to define the relationships sufficiently to design further research to quantify the contributions which different soil components make to the multispectral characteristics of specific soils. The ultimate objective of this research approach is to provide a body of knowledge and interpretive skills which will render remote multispectral sensing a valuable tool for mapping soils, determining land use capabilities and soil productivity ratings, identifying crops and predicting crop yields.

3. EXPERIMENTAL APPROACH

3.1 Stratification and Sampling

Approximately 250 soils, representing a statistical sampling of the more than 10,000 soil series in the United States were selected for this investigation. Selections were made from a list of the more than 1300 Benchmark soil series representing those soils with a large geographic extent and whose broad range of characteristics renders these soils so widely applicable for study.

Stratification of soil sampling was based on series type location within climatic zones. Climatic strata included the frigid, mesic, thermic, and hyperthermic soil temperature regimes as defined by the U.S. Soil Taxonomy (5,6,7) as well as the perhumid, humid, subhumid, semiarid, and arid moisture regions as identified by Thornthwaite's 1948 Moisture Index (8). A random selection procedure was used within each stratified climatic zone to select a number of soils series approximately in proportion to the geographic extent of that region. Resulting sample distribution by climatic region for the soils actually received is shown in Table D-1.

Considerations were also made to include soils which represent the major parent material categories and the ten soil orders of the U.S. Soil Taxonomy (5). Table D-2 presents the distribution of the Benchmark soil series on-hand according to soil parent material. As can be seen in Table D-3, the distribution of Benchmark soils used for this study is very similar to the areal extent of the nine soil orders found in the continental United States (Oxisols being absent in the contiguous states).

The type of clay mineralogy present in a soil is also known to influence its reflectance characteristics (3,4). The mineralogy classes, one of the family differentiae for mineral soils in the U.S. Soil Taxonomy (5), are listed for the Benchmark soils on-hand in Table D-4.

Table D-1. Distribution of soils by climatic region.

Climatic Region	Number of Benchmark Soil Series
1. Perhumic Mesic	6
2. Humid Frigid	18
3. Humid Mesic	37
4. Humid Thermic	30
5. Humid Hyperthermic	6
6. Subhumid Frigid	21
7. Subhumid Mesic	23
8. Subhumid Thermic	18
9. Subhumid Hyperthermic	2
10. Semiarid Frigid	9
11. Semiarid Mesic	24
12. Semiarid Thermic	10
13. Semiarid Hyperthermic	5
14. Arid Frigid	2
15. Arid Mesic	16
16. Arid Thermic	12
17. Arid Hyperthermic	1
	240 total

Table D-2. Distribution of soils by parent material.

Parent Material	Number of Benchmark Soil Series
Rocks weathered in place	
Igneous	10
Sedimentary	27
Metamorphic	1
Soft rock residuum	5
Transported materials	
Alluvium (general)	38
Calcareous	11
Non-calcareous	15
Colluvium	3
Lacustrine	4
Marine sediments	16
Loess	29
Other eolian sediments	8
Glacial drift	
Till	29
Calcareous till	5
Glaciofluvial deposits	4
Glacial outwash	4
Glaciolacustrine materials	2
Organic materials	2
Loamy sediments	17
Silty sediments	4
Calcareous silt loam	3
Marsh deposits	1
Pedisediments	2
	240 total

Table D-3. Distribution of soils by Soil Order.

	Benchmark Soils		United States Extent
	Number	Percent	Percent
Mollisol	73	30.4	24.6
Alfisol	40	16.7	13.4
Entisol	39	16.2	7.9
Aridisol	25	10.4	11.5
Ultisol	22	9.2	12.9
Inceptisol	18	7.5	18.2
Spodosol	15	6.2	5.1
Vertisol	4	1.7	1.0
Histosol	4	1.7	0.5
total	240		

Table D-4. Distribution of soils by mineralogy classification.

Class	Number of Benchmark Soil Series
Mixed*	176
Montmorillonitic	35
Siliceous	17
Carbonatic	5
Kaolinitic	3
Gypsic	2
Micaceous	2

*Designates class with <40% of any one mineral other than quartz or feldspars.

3.2 Acquisition of Soil Samples

The Soil Survey Investigations Division of the Soil Conservation Service (USDA) cooperated with LARS in the collection of field samples from 39 states. Duplicate field samples were collected for all Benchmark soil series requested: one sample from a site near the type location for the current official series, and one sample from a site located from one to 32 kilometers from the first site and in a different mapping delineation. Soil Conservation Service field survey personnel were responsible for sample collection of Benchmark soils in their locality. Of the original list of approximately 250 Benchmark soils requested, the Soil Conservation Service has collected, properly identified, and forwarded 240 Benchmark soils, or 480 duplicate soil samples to LARS. This excellent response of over 95 percent of the requested samples forms an outstanding collection of soil samples for detailed chemical, physical, and spectral analysis. All samples conform to the central concept of each individual soil series as each soil would be identified and mapped by an experienced soil surveyor in the field.

3.3 Preparation of Soils for Analysis

After receipt of the soil samples and initial data logging, samples were dried, crushed, and sieved to remove all particles larger than 2 mm diameter. Cardboard containers were used to store subsamples of each soil sample for chemical, physical, spectral, and engineering determinations.

3.4 Spectral Measurements

The Exotech Model 20C was used in an indoor configuration with the bidirectional reflectance factor reflectometer (9, 10) in order to obtain spectral readings in the 0.52-2.32μm wavelength range. The illumination source was a 1000 watt tungsten iodine coiled filament lamp which transfers a highly collimated beam by means of a paraboloidal mirror to the sample-viewing plane. Detector height above the sample was 2.44 m, and a $3/4^{o}$ field of view required that the sample holder be approximately 10 cm in diameter.

Because of the need to provide an equipotential condition for spectroradiometric analysis of the prepared soil samples, a procedure was chosen which creates a PF2 soil moisture tension on all the soil samples (11,12). Two asbestos tension tables were constructed and a 100 cm column of water was established to create a PF2 (approximately one-tenth bar) soil moisture tension for up to 56 soil samples at one time. Sample holders were designed and constructed of plastic rings 2 cm deep by 10 cm in diameter with 60 mesh brass strainer cloth stretched taut and fastened in a countersunk groove in one end. Sample holders were painted with non-reflecting black paint to reduce unwanted reflection external to the target of interest.

After saturation of the soil filled, leveled sample holders for about four hours, the samples were placed on the tension tables for 24 hours in order to reach equilibrium. The PF2 moisture tension was desirable mainly for the ease with which large numbers of samples could be prepared at equipotential moisture characteristics. Shortly after placement of each sample holder on the sample table of the reflectometer for spectral readings, a portion of the sample was transferred to a moisture tin, weighed, dried in a forced air oven at $105^{o}C$, weighed again, and moisture content reported as percentage of oven dry weight. The setup for indoor spectral measurements of soils is shown in Figure D-1.

3.5 Measurement of Physicochemical Properties

Facilities of the Purdue University Agronomy Department were used to perform the following analyses: mechanical analysis (eight particle size separates), organic matter content, cation exchange capacity, and iron oxide content. Other associated measurements to be taken are shown in Figure D-2. Because of the late arrival of many of the soil samples, mechanical analysis and iron oxide analysis are still in progress, while cation exchange capacity measurements have been completed.

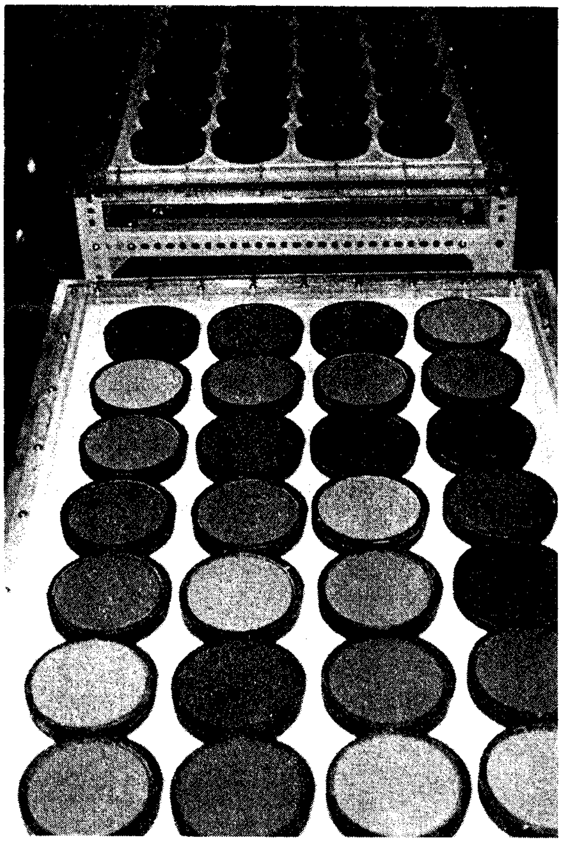
3.6 Measurement of Engineering Properties

The following engineering properties are being determined in the facilities of the Purdue University Department of Geosciences: liquid limit, plastic limit, plasticity index, activity, liquidity index, volumetric shrinkage, and compression index. Coding of these measurements

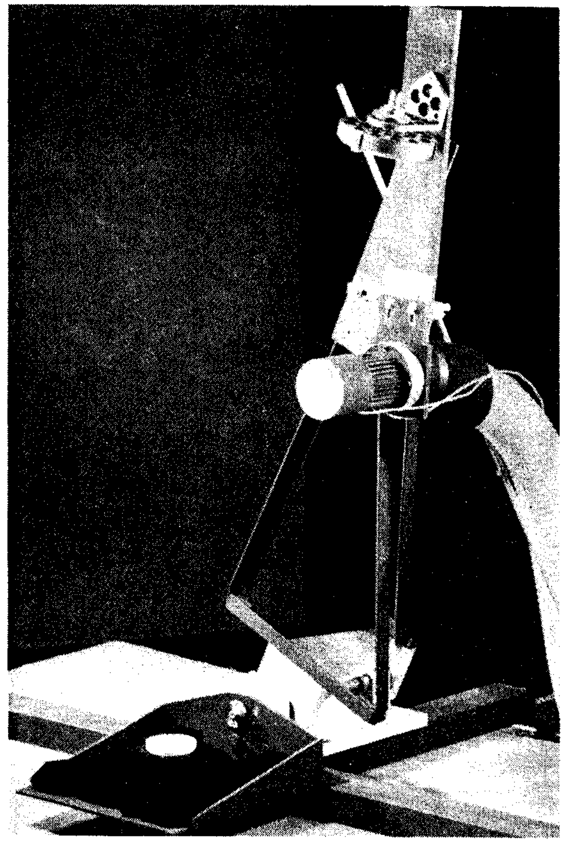
a. 10 cm diameter sample holder with soil container.

b. Saturated sample being placed on asbestos tension table.

Figure D-1. Setup for laboratory spectral measurements of soils.



c. 56 soil samples ready for spectral measurement after 24 hours equilibration at 100 cm H_2O tension.



d. BRF reflectometer positioned for soil sample detection.

Figure D-1 (Cont.)

and resulting engineering soils classifications can be seen in Figure D-2.

Of the 226 soils processed thus far, 173 or 77% have contained enough of the sub-.425 mm fraction to run the battery of Atterberg and associated tests (13). The remainder of the soils are sands and exhibit virtually no cohesive properties at all.

The measured data values for the engineering properties are representative of the data values given on the established series description sheets for the soil series and agree well, where comparison is possible. Major variations in properties did occur in a few cases between the duplicate samples of a given soil, but in general, measurements of engineering properties between duplicate samples were in agreement.

3.7 Establishment of Data Logging Procedure

An identification record containing complete soil taxonomic information along with site characteristics and laboratory analysis results has been prepared and implemented for storage and rapid retrieval as part of the EXOSYS software package (14). The record consists of seven computer cards of information for each observation (Figure D-2).

4. RESULTS OF SOIL SPECTRAL MEASUREMENTS

The bulk of the soil spectral measurements were made on nine days from August 29 to September 15, 1978 with 56 soil samples being analyzed each day. Additional measurements were taken on October 20, 1978 for late-arriving soil samples. During this time period the Exotech Model 20C spectroradiometer was being used for outdoor spectral measurements, but it was possible to dismount the detector head and position it in the optics laboratory in the evening after taking outdoor daytime measurements. Connector cables were passed through a wall port for connection of the detector head with the recording instruments in a van parked outside. Careful alignment of the reflectometer setup with the detector helped to insure repeatability of experimental conditions.

Reformatting of the spectral measurement data and filing of the data on a sequential run tape was completed on November 10, 1978. Preliminary

PURDUE/LARS SOILS RECORD SHEET NO. 1

Location	Dates of Corresponding Instrument Data					Dates Soils Data Collected		Investigator
					1			

Descr. Code	Treatment Level Or Factor No. 1 2 3 4 5 6	Parent Material	PFO	Soil Taxonomy Classification: Order	Suborder	Great Group	Particle Size Class	Contrasting Particle Size	Mineralogy	Other Modifiers	Temperature Reg.	Moisture Zone	Drainage Class	Slope Class	Erosion Phase	Physiographic Position	Soil Taxonomy Subgroup Name	Soil Series Name	Soil Survey Sample Number (coded for year, state, county)

PURDUE/LARS SOILS RECORD SHEET NO. 2

Cover Code	Horizon	BP	Soil Testing Lab Number	Organic Carbon (%)	Water pH	Buffer pH	Extractable Bases (me/100g) Ca	Mg	Na	K	Extractable Acidity	CEC Sum	Base Saturation (%)	Fe_2O_3 (%)	Al_2O_3 (%)	MnO_2 (%)	SiO_2 (%)	Available P Kg/ha	K Kg/ha

PURDUE/LARS SOILS RECORD SHEET NO. 3

Cover Code	Soil Moisture Tension (Bars)	Water Content (%)	Bulk Density g/cm³	DP	Munsell Color Moist: Hue	Value	/ Chroma	Textural Class (Material <2mm)	USDA Particle Size Distribution (mm) (Percent of <2mm Fraction) Total: Sand (2-.05)	Silt (.05-.002)	Clay (<.002)	Sand: V. Coarse (2-1)	Coarse (1-.5)	Medium (.5-.25)	Fine (.25-.10)	V. Fine (.10-.05)	Silt: Coarse (.05-.02)	Fine (.02-.002)	Electrical Conductivity mmhos/cm	Erosion Factor K	Wind Erodibility Group

Figure D-2. EXOSYS soil record sheets for header record data logging.

PURDUE/LARS SOIL RECORD SHEET NO. 4

Obser. Code	Engineering Lab Number	Sample Portion <.425/<2mm	Engineering Tests (based on <.425mm Fraction)										ASTM Particle Size Distribution			Specific Gravity g/cm³	AASHO Soil Classification	Unified Soil Classification	Experimentors Parameters (real numbers)		
			Liquid Limit	Plastic Limit	Plasticity Index	Activity	Liquidity Index	Shrinkage Limit	Shrinkage Ratio	Volumetric Shrinkage	Linear Shrinkage	Compression Index	Med. Sand (2-.425)	Fine Sand (.425-.075)	Fines (<.075)				#1	#2	#3

PURDUE/LARS SOILS RECORD SHEET NO. 5

Obser. Code	Soil Elevation (meters)	Experimentor's Parameters (real numbers)									
		#4	#5	#6	#7	#8	#9	#10	#11	#12	#13

PURDUE/LARS SOILS RECORD SHEET NO. 6

Obser. Code	Natural Vegetation or Crop	Surface Condition or Tillage-Planting System	Comments

PURDUE/LARS SOILS RECORD SHEET NO. 7

Obser. Code	Comments (cont.)	Comments (cont.)

Figure D-2 (Continued)

analysis of the data has shown all measurements to be of excellent quality. Initial data analysis included primarily graphical display of soil spectral measurements of interest. Statistical analysis will follow upon completion of header record information for each soil sample.

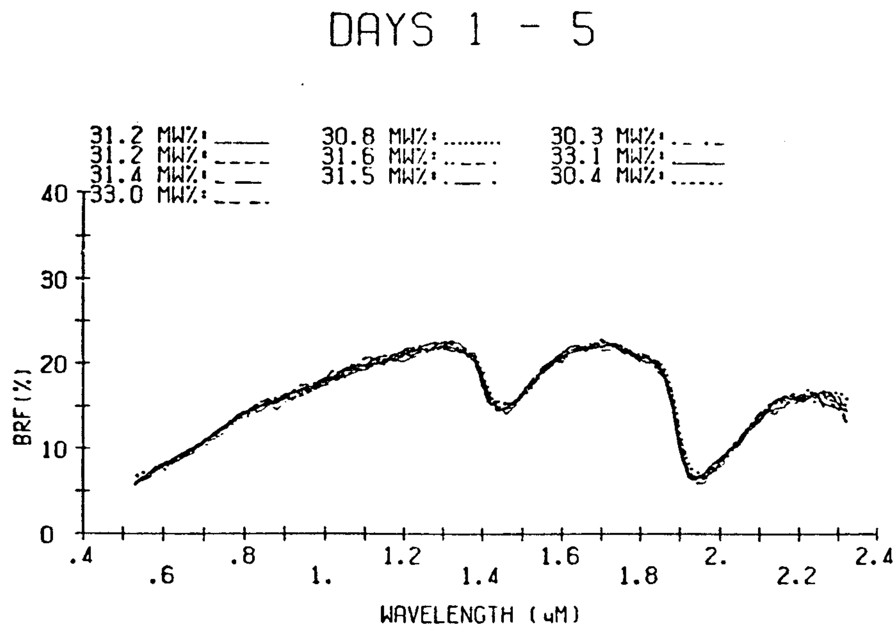
4.1 Evaluation of Experimental Procedures

During each of the ten days in which soil spectral measurements were taken, two check samples were randomly assigned to each block of 56 soil samples as a verification of repeatability of the tension table setup as well as the instrument setup. The check samples consisted of subsamples of a larger field sample of Fincastle silt loam soil (Aeric Ochraqualf). Figure D-3 presents the spectral curves for these 20 check samples, divided into two time blocks for sake of illustration. Soil moisture content, or more correctly, soil moisture weight percent (MW%) as measured gravimetrically after taking spectral readings is shown. As can be easily seen, moisture weight percent varied little from an average 31.3 MW% for all check samples, while the spectral response curves are remarkably similar for all days and setups.

4.2 Representative Soils from Different Soil Orders, Climatic Zones, and Having Different Mineralogy Classes

The diversity of soil spectral response is evident from the soil curves presented in Figure D-4. As listed in Table D-5, all ten soil orders of the U.S. Soil Taxonomy are represented here, including four Oxisols from Brazil which were included to contrast with what has conventionally been thought of as the "typical" soil reflectance curve.

Each pair of curves for a given soil series represents the duplicate field samples which may vary in certain soil characteristics within an allowable range permitted for that soil series. For example, small differences in clay content or organic matter content may in themselves affect soil reflectance while at the same time directly influencing the moisture weight percentage in soil samples equilibrated at an equipotential moisture tension. It is generally recognized that increased moisture weight percentage results in decreased soil reflectance throughout the 0.4 to 2.5 um wavelength range (1,4,15). This soil moisture influence



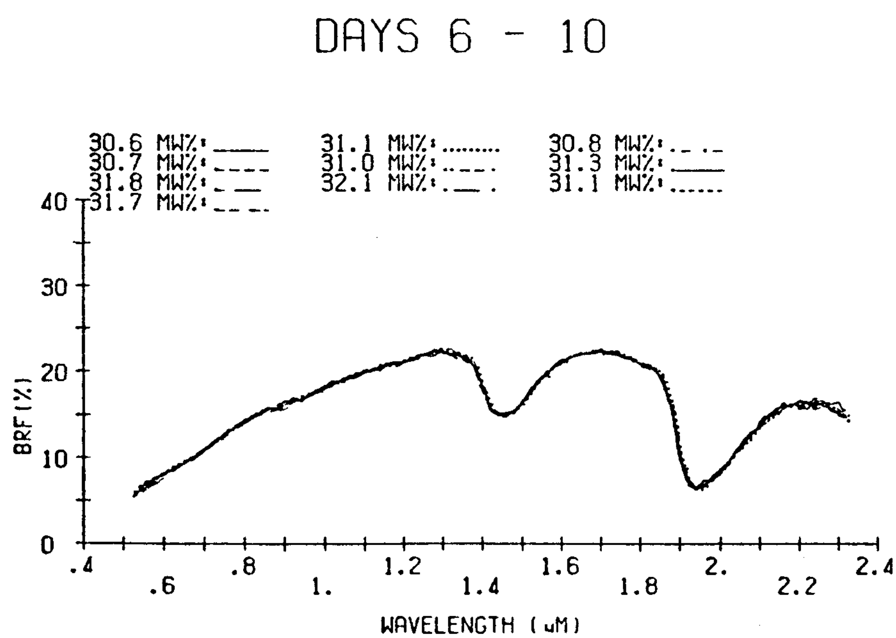


Figure D-3. Soil spectral curves and moisture weight percentages (MW%) for 20 check samples from ten different setups of the tension table apparatus with resultant reflectance measurements.

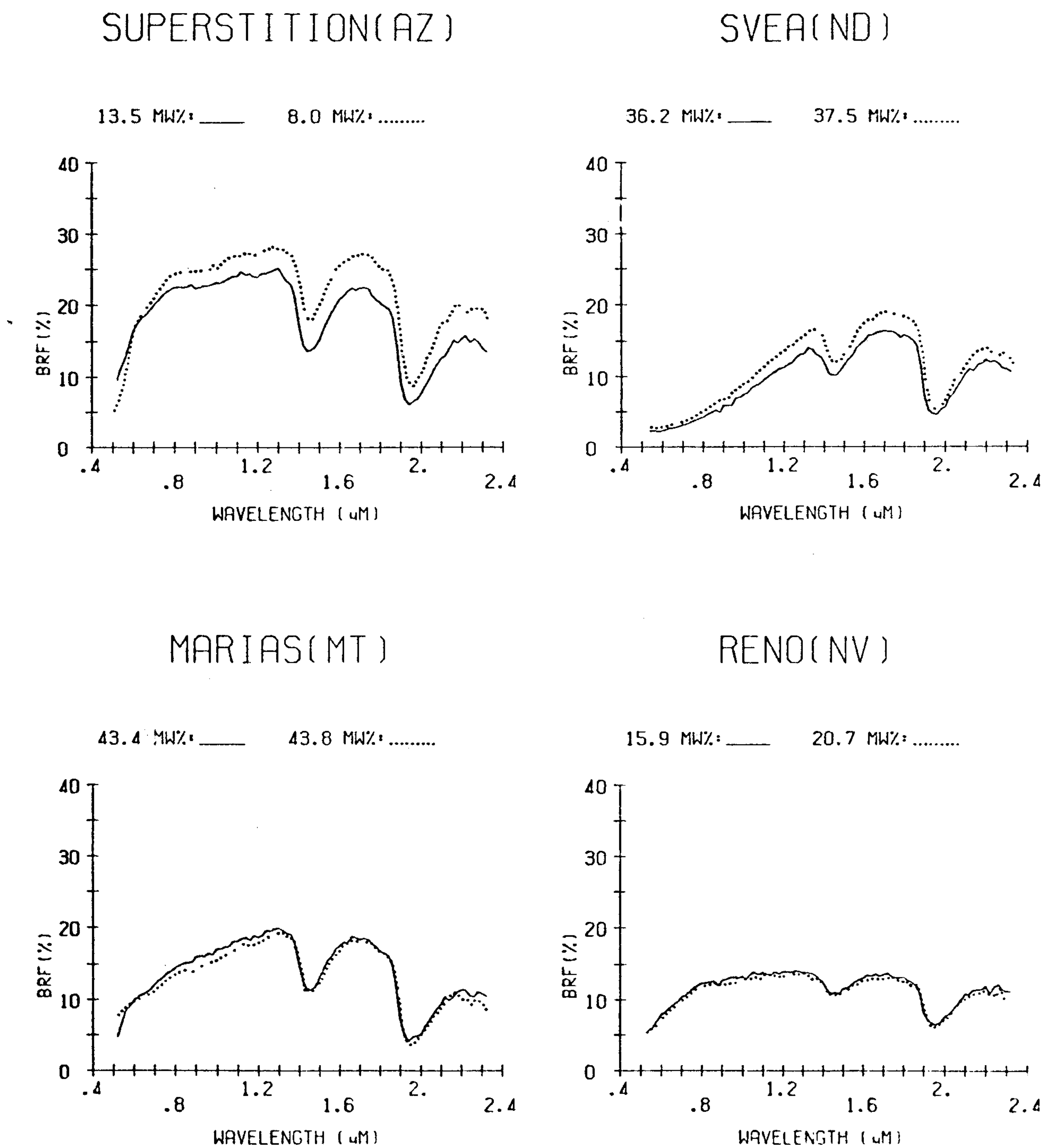


Figure D-4. Spectral response curves for duplicate samples of sixteen soil series from a broad range of soil orders, climatic zones, and mineralogy classes (refer to listing, Table D-5).

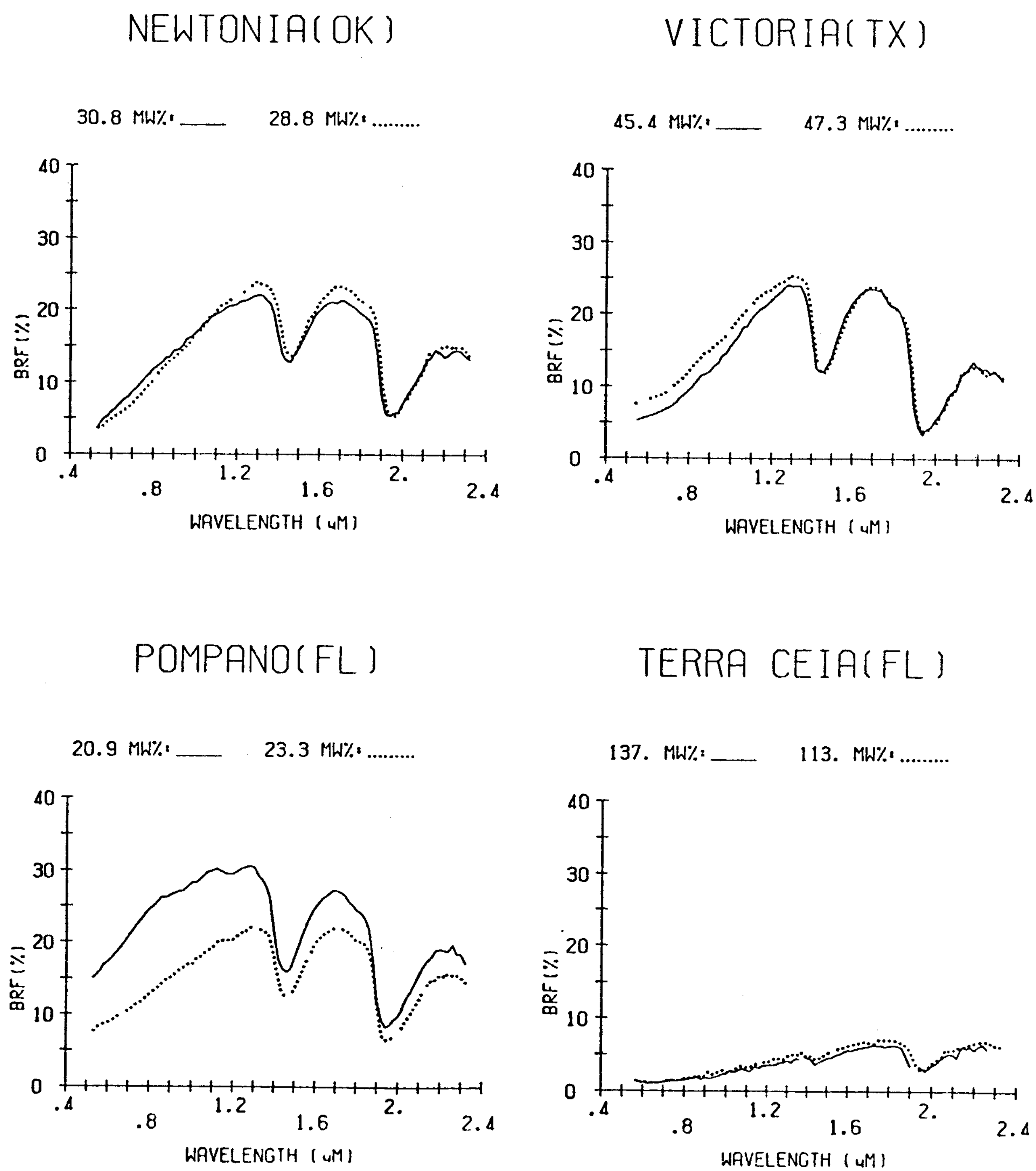


Figure D-4. (Continued)

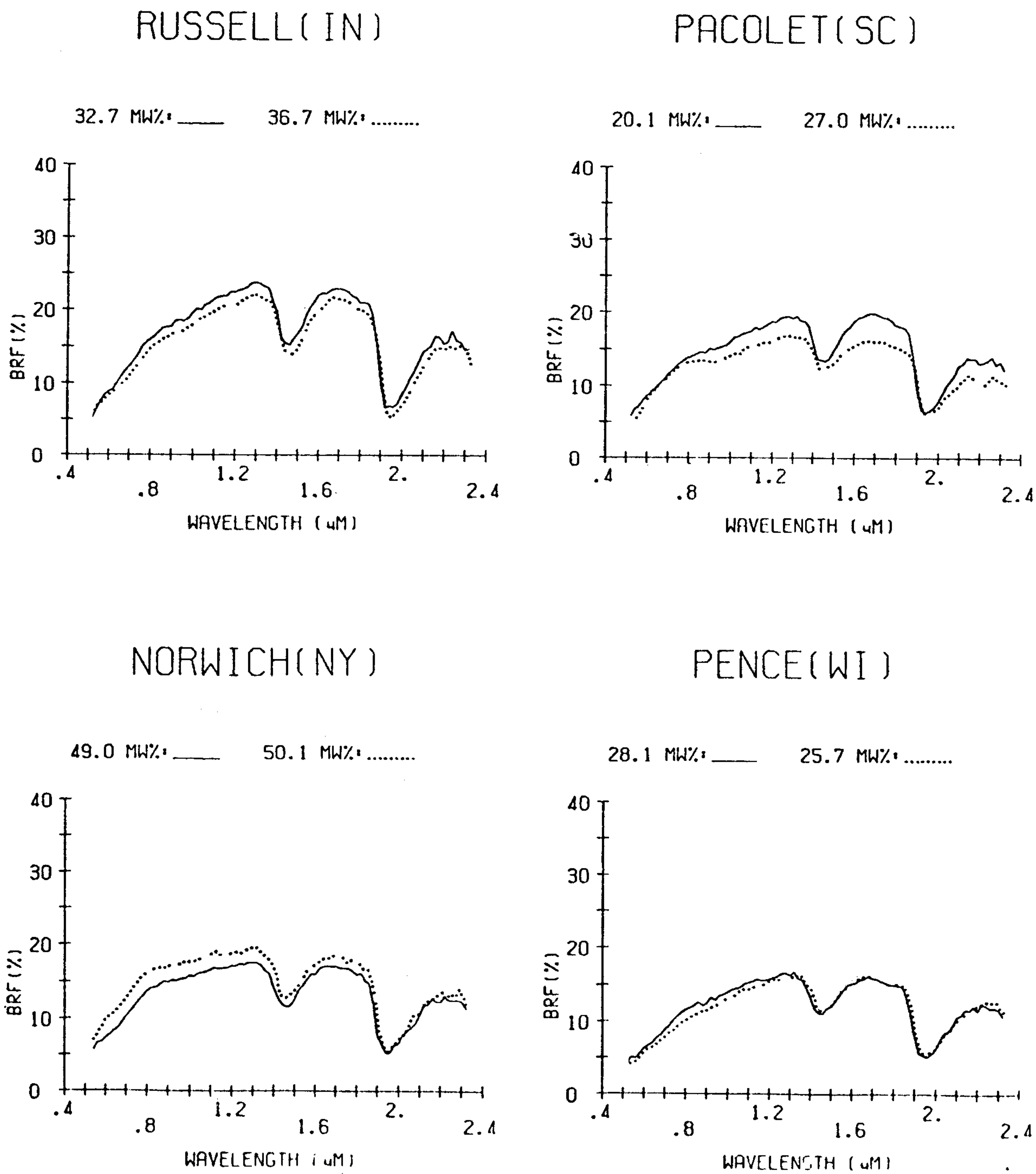


Figure D-4. (Continued)

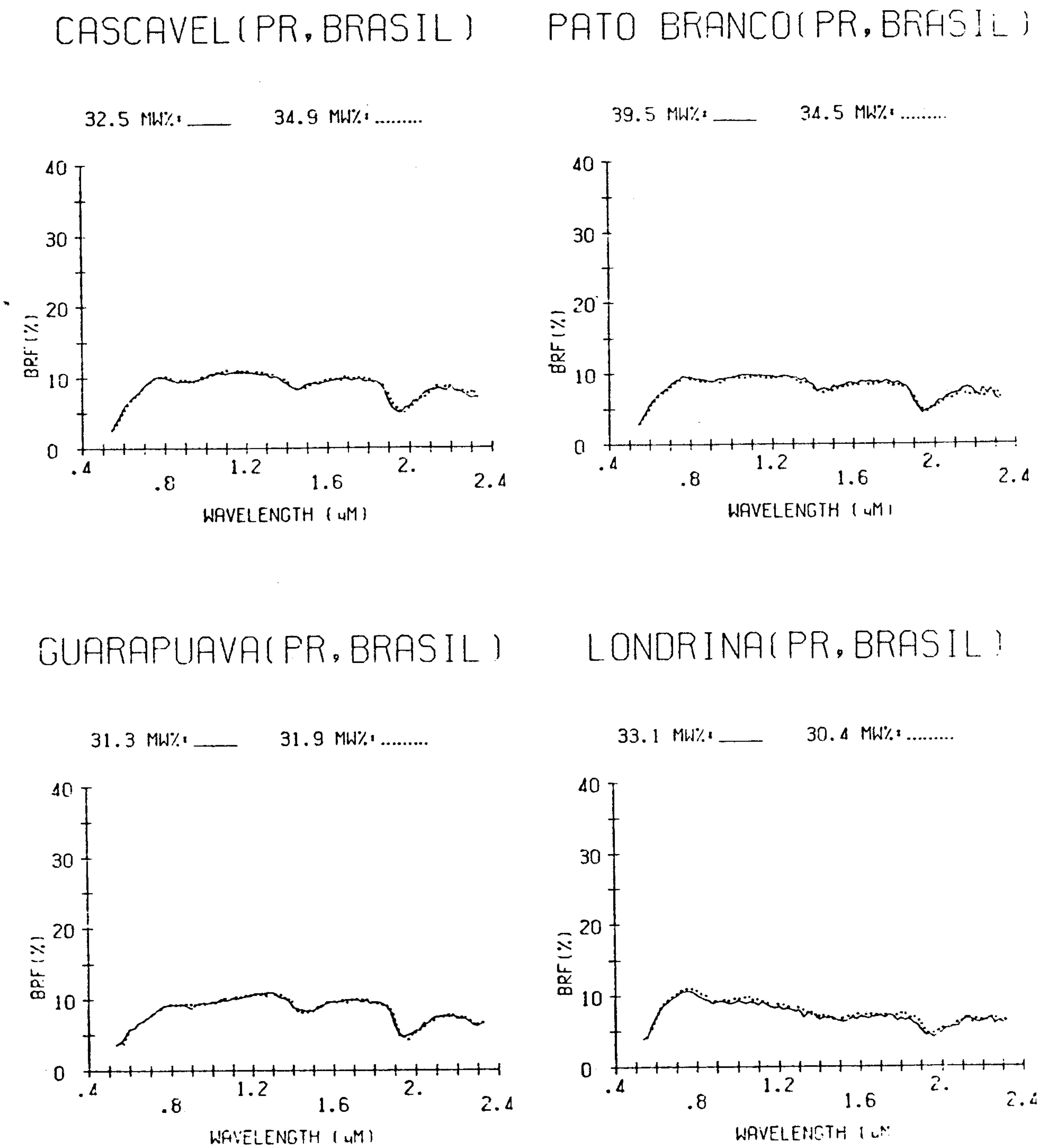


Figure D-4. (Continued)

Table D-5. Representative soils of ten Soil Orders with various mineralogy classes and from different climatic zones (refer to Figure D-2).

	Taxonomic Classification			
Soil Series Name (State)	Order	Subgroup	Climatic Zone	Mineralogy Class
Superstition (AZ)	Aridisol	Typic Calciorthid	Arid Hyperthermic	Mixed
Svea (ND)	Mollisol	Pachic Udic Haploboroll	Subhumid Frigid	Mixed
Marias (MT)	Entisol	Ustertic Torriorthent	Semiarid Frigid	Montmorillonitic
Reno (NV)	Aridisol	Abruptic Xerollic Durargid	Semiarid Mesic	Montmorillonitic
Newtonia (OK)	Mollisol	Typic Paleudoll	Humid Thermic	Mixed
Victoria (TX)	Vertisol	Udic Pellustert	Subhumid Hyperthermic	Montmorillonitic
Pompano (FL)	Entisol	Typic Psammaquent	Humid Hyperthermic	Siliceous
Terra Ceia (FL)	Histosol	Typic Medisaprist	Humid Hyperthermic	(organic soil)
Russell (IN)	Alfisol	Typic Hapludalf	Humid Mesic	Mixed
Pacolet (SC)	Ultisol	Typic Hapludult	Humid Thermic	Kaolinitic
Norwich (NY)	Inceptisol	Typic Fragiaquept	Humid Mesic	Mixed
Pence (WI)	Spodosol	Typic Haplorthod	Humid Frigid	Mixed
Cascavel (PR, Brazil)	Oxisol	Haplic Acrorthox	Humid Thermic	Oxidic
Pato Branco (PR, Brazil)	Oxisol	Haplic Acrorthox	Humid Thermic	Kaolinitic
Guarapuava (PR, Brazil)	Oxisol	Typic Acrohumox	Humid Thermic	Oxidic
Londrina (PR, Brazil)	Oxisol	Typic Haplorthox	Humid Hyperthermic	Kaolinitic

can be seen in many of the duplicate samples in Figure D-4, although moisture alone is not responsible for this overall "darkening" effect.

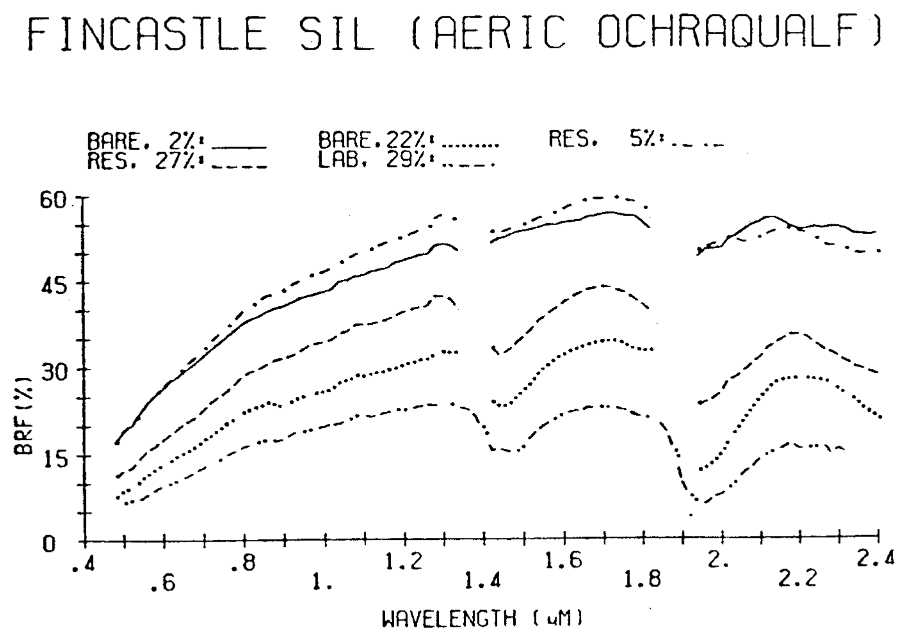
Aside from the obvious soil water absorption bands at 1.44 and 1.94um, a small, yet distinct absorption band can be seen at 2.2 um in the Pacolet (SC), Marias (MT), and other soils. This band has been attributed to the hydroxyl group and is especially prominent in kaolinite and montmorillonite clays. Another broad, but well defined absorption band is that at 0.9 um, attributed to iron oxides in the soil. This band is obvious in all four Oxisols from Parana State, Brazil, some of which have iron oxide contents as high as 25%.

4.3 Comparison of Laboratory and Field Spectral Data

Results illustrated in Figure D-5 indicate that a comparison can be made between field measured soil plots under solar illumination and laboratory measured soil samples under artificial illumination when all spectral measurements are compared to a $BaSO_4$ standard. The general trends of the curves for each soil are similar no matter whether the measurements were taken in the lab, or in the field under four different surface conditions: bare dry soil, bare moist soil, residue-covered dry soil, or residue-covered moist soil (cut-offs in field measured curves represent attenuation of solar illumination source). This concept is an important one--that a given soil has a wide range of spectral reflectance characteristics defined by specified conditions of irradiation and viewing and varying according to naturally occuring states of surface roughness, residue amount, and green vegetative cover.

4.4 Comparison of Soils with Differing Engineering Properties

Illustrations of the spectral curves of four soils of interest are given in Figure D-6. The pertinent behavioral data are given in Table D-6. The Abbott is a fine, montmorillonitic clay from the arid mesic climatic zone of Millard County, Utah. It experienced a volumetric shrinkage rate of 101 making it a soil which would be of some concern in foundation design due to the potential for a large amount of swelling upon wetting. This would be of particular concern in using slab foundations in this arid area.



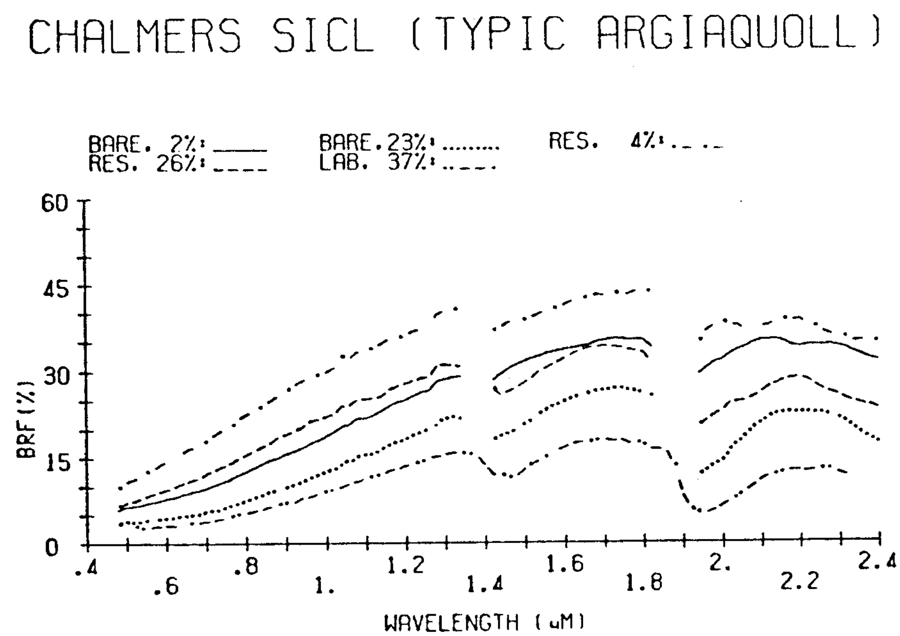


Figure D-5. Comparison of two soils measured in the field and in the laboratory. Percentage figures are moisture weight percent; RES = corn residue cover of 35%; BARE = residue free field plots; LAB = laboratory data.

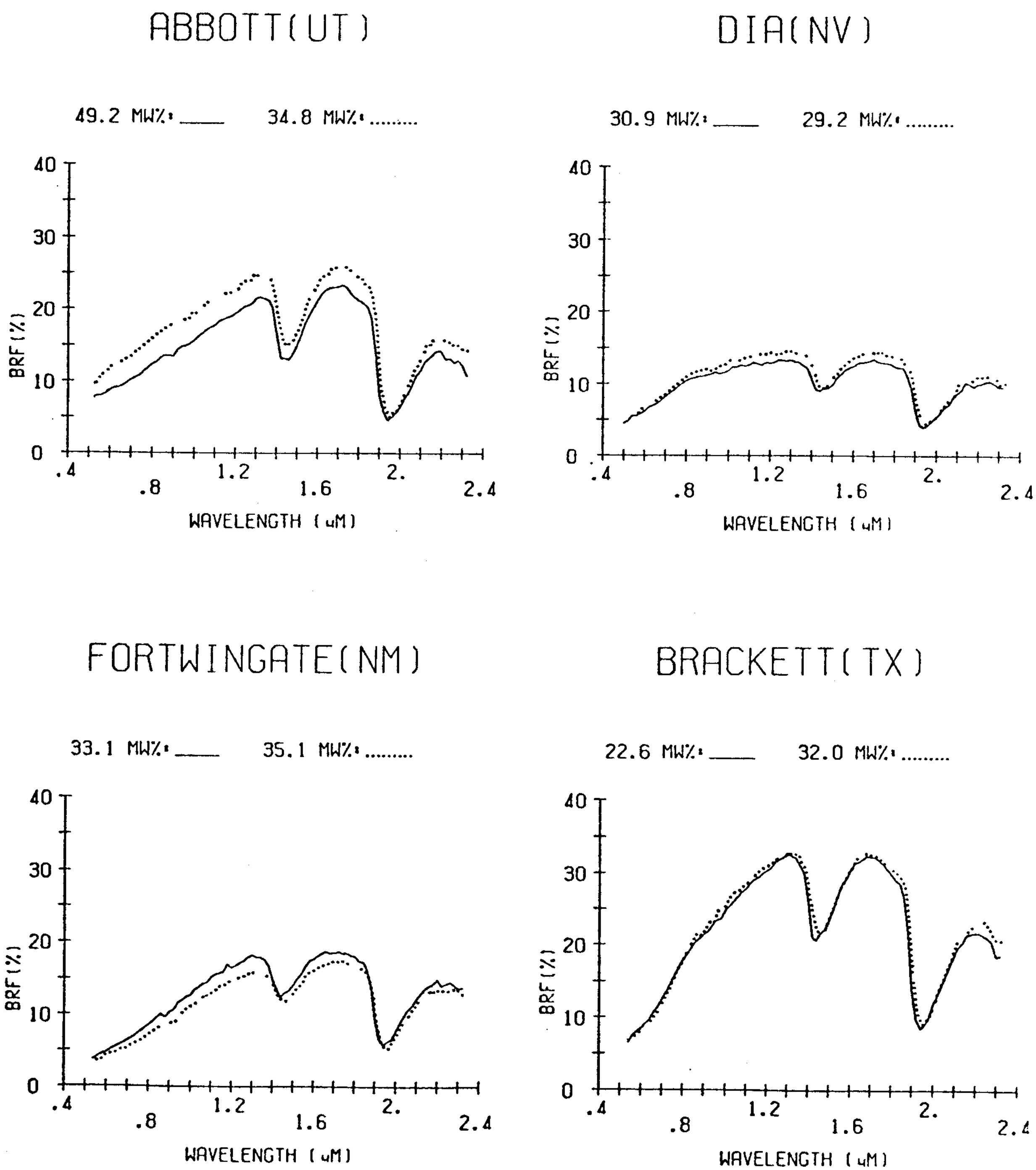


Figure D-6. Comparison of four soils with differing engineering properties.

Table D-6. Engineering properties of duplicate soil samples illustrated in Figure D-6.

Property	Abbott		Dia		Brackett		Fortwingate	
Liquid limit	61	52	39	31	31	39	27	33
Plastic limit	25	24	22	23	23	31	21	22
Plasticity index	36	28	17	8	8	8	6	11
Activity	N/A	N/A	0.95	0.50	0.38	0.28	0.43	0.56
Shrinkage limit	17	15	20	19	16	23	21	18
Shrinkage ratio	1.8	1.8	1.7	1.7	1.8	1.6	1.7	1.1
Volumetric shrinkage	101.0	85.3	42.0	29.2	41.4	38.4	19.9	19.8
Linear shrinkage	20.1	18.5	11.0	8.1	10.8	10.2	5.9	5.8
Compression index	.439	.318	.261	.189	.189	.261	.153	.207
ASTM Particle Size Distribution								
medium sand (2-.425 mm)	00.8	00.9	8.5	5.4	9.1	8.2	00.3	00.2
fine sand (.425-.075 mm)	09.5	10.1	42.1	54.3	32.3	19.1	46.5	24.7
fines (<.075 mm)	89.7	89.0	49.4	40.3	58.6	72.7	53.2	75.1
Specific gravity	2.61	2.43	2.47	2.48	2.50	2.44	2.52	1.38
AASHO classification	A-7	A-7	A-6	A-6	A-6	A-6	A-6	A-6
Unified classification	CH	CH	CL	ML	ML	ML	CL	CL
Cation exchange capacity	49.8	44.4	23.1	26.7	23.7	26.7	15.6	33.9
Clay content	N/A	N/A	17.9	16.1	21	28.1	13.9	19.5

Dia, a fine loam from the arid mesic climatic zone of Churchill County, Nevada, and Brackett, a loam from the subhumid thermic climatic zone of Bell County, Texas typify the majority of the soils studied with respect to their engineering properties. They exhibit moderate liquid limits and volumetric shrinkage readings, and are well-graded. Variation between duplicate samples are low. The spectral curves agree with what was expected given the moisture content at which the readings were taken and the clay content of the sample.

The Fortwingate soil is a friable loam from the semiarid mesic climatic zone of McKinley County, New Mexico. It exhibited the lowest volumetric shrinkage reading to date. It is better graded than the Abbott and has a lower cation exchange capacity. In comparing the Abbott soil with the Fortwingate soil it is evident that the low shrink-swell soil, the Fortwingate, does not have as large a water absorption band at 1.4 um as the high shrink-swell soil, the Abbott. This may indicate a spectral region of the soil response curve useful for the prediction of high shrink-swell conditions which would be of concern to the engineer.

5. STATISTICAL ANALYSES

Upon completion of the measurements of spectral, chemical, and physical properties, all data will be entered into the soils data record in preparation for the statistical analyses. Several approaches are anticipated: (1) analysis of the variability of individual soil properties relative to the duplicate samples of a given soil series, (2) analysis of the degree to which soil series can be uniquely distinguished for individual properties, and (3) analysis of the possiblity of separating Benchmark soils on the basis of their reflectance characteristics.

Measured soil properties will be analyzed for normality and homogeneity of variances and appropiate transformations will be performed when needed. Analysis of variance will be used to test for significance of spectral differences between duplicate soil samples and among soil series. If warranted by the analysis of variance tests, multivariate analysis will be performed for relating the response in selected combinations of wavelength bands to chemical, physical, and engineering properties for soil samples grouped according to climatic zone and parent material categories.

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